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PREFACE.

THIS volume of the *Journal of the Iron and Steel Institute* contains the Report of the Proceedings of the Forty-eighth Annual Meeting, held in London in May 1917, with all the Papers presented on that occasion and the discussions and correspondence which took place thereon. The Notes on the Progress of the Home and Foreign Iron and Steel Industries have as usual been appended.

28 VICTORIA STREET, LONDON, S.W. 1.
August 1917.

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THE

IRON AND STEEL INSTITUTE.

SECTION I.

MINUTES OF PROCEEDINGS.

ANNUAL MEETING, 1917.

THE FORTY-EIGHTH ANNUAL GENERAL MEETING of the IRON AND STEEL INSTITUTE was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday and Friday, May 3 and 4, 1917, Sir WILLIAM BEARDMORE, Bart., President, in the Chair.

The Minutes of the previous Meeting, held at the Institution of Civil Engineers on September 21 and 22, 1916, were taken as read and signed as a correct record.

APPOINTMENT OF SCRUTINEERS OF THE BALLOT.

Mr. Isaac E. Lester (West Bromwich) and Mr. H. Savage (London) were appointed scrutineers of the ballot, and on completion of their scrutiny it was subsequently announced that the following sixty-four candidates for membership and fifty-one candidates for associateship had been duly elected:

MEMBERS.

NAME.	ADDRESS.	PROPOSERS.
Allen, William Henry, M.Inst.C.E.	Queen's Engineering Works, Bedford	Sir Wm. Beardmore, Bart., W. H. Ellis, F. C. Fairholme.
Anderson, A. G. M.	25 Armadale Street, Armadale, Victoria, Australia	D. Baker, J. Smart, R. Boan.
Atha, Charles Gurney	The Manor House, Brigg, Lincs.	M. Mannaberg, Jas. Henderson, F. W. Harbord.
Atkinson, Ernest	5 Bank Road, Workington	T. W. Graham, G. J. Valentine, R. W. Burnyeat.

NAME.	ADDRESS.	PROPOSERS.
Atkinson, Fred	c/o The Amalgams Co., Ltd., Attercliffe Road, Sheffield	H. Brearley, M. R. Mainprice, A. W. Brearley.
Barnes, Kenneth Norman	Welbeck Lodge, Dale Street, Leamington	J. W. Fawcett, W. H. Hatfield, J. M. Lessells.
Beynon, John Wyndham	Castleton, near Cardiff	Sir Charles Allen, Frederick Mills, W. T. McLellan.
Biggin, Frank	19 Rupert Road, Nether Edge, Sheffield	I. B. Milne, R. H. Radford, P. B. Henshaw.
Blight, Francis James	"Tregenna," Wembley, Middlesex	Sir R. A. Hadfield, W. Gowland, J. E. Stead.
Bolsover, George Rowland	31 Rossington Road, Brocco Bank, Sheffield	F. C. Fairholme, W. H. Hatfield, M. E. Unwin.
Broomhead, Earl Clarence, B.Met.	28 Seagrave Road, Norfolk Park, Sheffield	J. O. Arnold, H. Brearley, T. G. Elliot.
Chambers, Ambrose	70 Old Whittington Hill, Chesterfield	E. Houghton, T. E. Holgate, M. Deacon.
Child, Walter Haydn.	Park Gear Works, Huddersfield	J. P. Bedson, L. Rothera, N. P. Bedson.
Cliff, Joseph T. T.	The Grove, Scawby, Brigg, Lincs.	M. Mannaberg, Jas. Henderson, A. Crooke.
Davies, Harry	7 Cambridge Crescent, Edgbaston, Birmingham	Thos. Turner, O. F. Hudson, H. Silvester.
Delprat, Guillaume Daniel	Equitable Building, Collin Street, Melbourne, Australia	D. Baker, Sir Wm. Beardmore, Bart., Illtyd Williams.
Donald, William	45 Renfield Street, Glasgow	Sir William Beardmore, Bart., Illtyd Williams, Arthur Cooper.
Edmiston, John Alexander C.	12 Melville Crescent, Motherwell	D. J. Pinkerton, D. M. Maclay, T. B. Mackenzie.
Fairhurst, George Henry	Bengal Iron & Steel Co., Kulti, E.I.R., Bengal, India	W. T. MacLellan, J. Angus, J. H. Harrison.
Foster, Frank, M.Sc.	7 Victoria Road, Whalley Range, Manchester	H. Pilling, T. C. Hutchinson, P. Williams.
Graham, The Right Hon. the Marquis of	Brodick Castle, Isle of Arran, Scotland	Sir William Beardmore, Bart., Sir R. A. Hadfield, Arthur Cooper.
Green, George William	Messrs. Sir W. G. Armstrong, Whitworth & Co., Ltd., Openshaw, Manchester	E. F. Law, C. A. Edwards, J. H. Andrew.
Greig, Edward Cockburn	2 Cliff Gardens, Frodingham, Lincs.	M. Mannaberg, A. Crooke, Jas. Henderson.
Griffiths, Ernest, M.I.Mech.E.	138 Vauxhall Road, Liverpool	Col. J. R. Wright, Col. W. Charles Wright, J. C. Davics.
Hague, Alexander Parker	284 Granville Road, Norfolk Park, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.

NAME.	ADDRESS.	PROPOSERS.
Hammarström, Hjalmar Georg	Nyhammar, Sweden	E. Klintin, I. Olsson, H. Diedrich.
Hand, Thomas Wilton	4 Brentwood Avenue, Sheffield	A. J. Capron, W. H. Ellis, F. C. Fairholme.
Hardy, Thomas Woodburn, Jnr., B.Sc.	c/o Nova Scotia Steel & Coal Co., New Glasgow, N.S.	R. A. Newbould, A. Sauveur, H. M. Boylston.
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Hoyland, Colin George	237 Western Bank, Sheffield	W. H. Thomas, J. Pettigrew, J. H. Fisher.
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Lloyd, Frederic	Alma Street, Sheffield	T. Rowlands, W. Farrar, H. H. Best.
Main, Sidney Arthur, B.Sc.	57 Wilkinson Street, Sheffield	Sir R. A. Hadfield, I. B. Milne, W. J. Dawson.
Mantelli, A. S.	Piazza Cavour 35, Genoa, Italy	C. Fera, V. Sevieri, J. T. Milton.
Nancollas, Henry Philip	Braeside, New Road, Llanelly	W. W. Johnson, Stanley R. Davies, F. W. Gilbertson.
Ogilvie, Allan	Frodingham Iron and Steel Co., Ltd., Frodingham, Lincs.	M. Mannaberg, A. Crooke, Jas. Henderson.
Orlando, Giuseppe	Piazza Venezia 11, Rome	Sir William Beardmore, Bart., Illtyd Williams, Arthur Cooper.
Parker, William Edwin	54 Brocco Bank, Sheffield	Sir R. A. Hadfield, I. B. Milne, W. J. Dawson.
Primrose, Harry Stewart	National Forge and Foundry, Braintree, Essex	J. S. G. Primrose, P. N. Cunningham, J. R. Cunningham.
Pugsley, Thomas Montague	17 Osgathorpe Road, Pitsmoor, Sheffield	J. Kent Smith, T. H. George, T. Inman.
Rawson, Thomas Gregory	The Cedars, Coal Lane, Borrowash, near Derby	P. N. Beeten, F. C. Ryland, I. E. Lester.
Riddell, Matthew	Dungoyne, Aytoun Road, Pollokshields, Glasgow	J. O. Arnold, E. Adamson, D. Rennie.
Ridge-Beedle, Peter Denniston	116 Hope Street, Glasgow	Sir R. A. Hadfield, Sir Wm. Beardmore, Bart., J. O. Arnold.
Ritchie, Ronald James Howson	Rondel, Nunthorpe, Yorks.	J. E. Stead, N. D. Ridsdale, H. A. Shaw.

NAME.	ADDRESS.	PROPOSERS.
Rowe, Reginald Henry Marshall	The Broken Hill Proprietary Co., Newcastle, N.S.W.	H. P. Smith, E. E. Wood, H. R. Davies.
Sanderson, Frederick Isidor	c/o Messrs. Wellman, Seaver and Head, Ltd., King's House, Kingsway, London, W.C.	B. W. Head, F. G. Smith, Jas. Smith.
Scott, Robert . .	Messrs. William Beardmore & Co., Ltd., Parkhead Steelworks, Glasgow	G. N. Cook, T. M. Service, J. McFarlane.
Sharp, Richard . .	10 Thornfield Road, Middlesbrough	Greville Jones, Arthur Cooper, Illtyd Williams.
Spencer, Thomas Richard	2 Linden Grove, Linthorpe, Middlesbrough	Sir Hugh Bell, Bart., W. L. Johnson, Greville Jones.
Spicer, Walter Sydney	28 Botanical Road, Sheffield	Sir R. A. Hadfield, I. B. Milne, W. J. Dawson.
Stuart, Sir Harold Arthur, K.C.S.I., K.C.V.O.	89 Gloucester Terrace, Hyde Park, W.	H. G. Turner, Sir William Beardmore, Bart., Illtyd Williams.
Teng, Jui Hui, B.Sc.	16 Ventnor Road, Cwmbran, Mon.	T. Turner, W. H. Whitehouse, O. F. Hudson.
Thomas, *Captain* Wyndham P.	Elsham Hall, Elsham, Lincs.	M. Deacon, F. T. Thomas, F. W. Gilbertson.
Thorneycroft, Wallace	Plean House, Plean, Stirling	M. Mannaberg, A. Crooke, Jas. Henderson.
Trimlett, Henry J. .	49 Lillieshall Road, Clapham Common, London, S.W.	C. Hood, Sir Hugh Bell, Bart., Illtyd Williams.
Tweedy, George Frederick	Neptune Works, Walker, Newcastle-on-Tyne	L. D. D. Brown, G. Ainsworth, Sir Hugh Bell, Bart.
Wang, Cheng-Fu, Ph.D.	Pengchihu Coal and Iron Company, Pengchi, South Manchuria	W. Campbell, H. M. Howe, B. Stoughton.
Webster, *Lieut.* Frederick, M.Eng.	Little Mancott, Hawarden, Chester	Sir William Beardmore Bart., Illtyd Williams, Arthur Cooper.
Whiteley, John Hampden	11 Cambridge Street, Saltburn	C. J. Bagley, J. Reay, E. Crowe.
Whiteley, William, M.Sc.	22 Myrtle Terrace, Sowerby Bridge, Yorks.	C. A. Edwards, J. H. Andrew, J. N. Greenwood.
Woodward, James Madison, jun.	Minnesota Steel Co., Duluth, Minn., U.S.A.	R. A. Bull, W. W. Coleman, A. W. Gregg.

Associates.

Name.	Address.	Proposers.
Airey, Lawrence Clark	80 Harcourt Road, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Anderson, Arthur G. .	22 Gray Street, Workington, Cumberland	T. W. Graham, G. J. Valentine, R. Sharp.
Ascroft, Frank . .	102 St. Mary's Road, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Beet, Arthur Edgar .	11 Hanover Sq., Broomhall, Sheffield	,, ,,
Belbin, Harry L. .	Moorhill, Totley Rise, near Sheffield	,, ,,
Benton, Edwin W. .	Canonfields, Hathersage, *viâ* Sheffield	Sir R. A. Hadfield, I. B. Milne, T. G. Elliot.
Biggin, Alfred Stanley	73 Brook Road, Meersbrook, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Boden, W. . . .	Mornington House, The Green, Matlock	,, ,,
Brown, Ronald Bower	8 Collegiate Crescent, Sheffield	,, ,,
Bull, Harry . .	26 Limpsfield Road, Brightside, Sheffield	,, ,,
Burnett, George Richard	21 Hunsley Street, Grimesthorpe, Sheffield	,, ,,
Capstick, Norman .	63 Carter Knowle Road, Sheffield	,, ,,
Casson, Louis Julian .	90 Upperthorpe, Sheffield	,, ,,
Dennis, Hubert Ronald	105 Wales Road, Kiveton Park, Sheffield	,, ,,
Garnett, Cecil Stevenson	12 Cross Street, Chesterfield	,, ,,
Goddard, Charles Eric	146 Grimesthorpe Road, Sheffield	,, ,,
Gray, Frank West .	9 Spring Hill, Crookesmoor, Sheffield	,, ,,
Gregory, Edwin, junr.	54 Lyons Street, Pitsmoor, Sheffield	,, ,,
Hadwick, Arthur Edwin	Fire Station, Rockingham Street, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Hague, Edward Wilson	284 Granville Road, Sheffield	W. H. Hatfield, J. W. Fawcett, M. E. Unwin.
Hall, John Ainger .	31 Havelock Street, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Hodgson, Cyril Cotton	33 Warwick Street, Rotherham	,, ,,
Holmes, Colin W. H. .	Bank House, Chesterfield	J. O. Arnold, M. Deacon, E. Houghton.
How, Henry Edmund.	71 Meersbrook Park Road, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Hurst, Horace Westmoreland	78 Chelsea Road, Nether Edge, Sheffield	,, ,,
Jarvis, S. E. . .	22 Tom Lane, Fulwood, Sheffield	,, ,,

NAME.	ADDRESS.	PROPOSERS.
Kayser, John Ferdinand	10 Broomgrove Road, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Lambert, Arthur George	Town End Farm, Greasboro', Rotherham	N. Royston, J. O. Arnold, B. W. Winder.
Lapatnick, Aaron .	30 Silver Street, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Lloyd, Trevor Wyndham	293 Dykes Lane, Wadsley, Sheffield	,, ,,
Lodge, Laurence Wilson	37 Unwin Street, Penistone, Sheffield	,, ,,
Ludgate, Bertram .	568 Barnsley Road, Sheffield	J. O. Arnold, J. H. Dickenson, H. Lodge.
Luff, Alfred Ernest .	29 Binfield Road, Meersbrook, Sheffield	Sir R. A. Hadfield, I. B. Milne, T. G. Elliot.
Manterfield, David .	74 Cannon Hall Road, Pitsmoor, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Middleham, Arthur .	218 Springvale Road, Sheffield	Sir R. A. Hadfield, I. B. Milne, T. G. Elliot.
Montgomery, William Ross	Westfield Road, Parkgate, Rotherham	J. O. Arnold, B. W. Winder, L. Dufty.
Nodén, George . .	7 Market Street, Eckington	,, ,,
O'Neill, Hugh . .	79 Bower Road, Sheffield	,, ,,
Pasley, Ernest . .	50 Mona Road, Steel Bank, Sheffield	,, ,,
Ridge, Charles William	30 Gluman Gate, Chesterfield	Sir R. A. Hadfield, I. B. Milne, T. G. Elliot.
Russell, *Lieut.* George A. V., R.E., Wh. Ex.	61st Broad Gauge Workshop Coy, R.E., A.D. 2, B.E.F., France	Sir William Beardmore, Bart., Illtyd Williams, Arthur Cooper.
Seil, Leonard . .	27 Brunswick Street, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Shaw, John K. . .	10 Burnside Avenue, Meersbrook, Sheffield	,, ,,
Smales, Conrad Alwyne	Devonshire House, Barrow Hill, Chesterfield	,, ,,
Sutton, Hubert . .	The Cliffe, Rainow Road, Macclesfield, Cheshire	C. A. Edwards, J. H. Andrew, J. N. Greenwood.
Swannack, Francis Charles	6 Carr Road, Walkley, Sheffield	J. O. Arnold, B. W. Winder, L. Dufty.
Thompson, William Herbert	Traffic Terrace, Barrow Hill, Chesterfield	,, ,,
Vinters, John Augustus	Thurcroft Road, Woodseats, Sheffield	,, ,,
Wilson, Francis .	14 Grange Crescent Road, Sheffield	,, ,,
Wood, Cyril . .	67 Peveril Road, Sheffield	W. H. Hatfield, W. J. Fawcett, M. E. Unwin.
Wrighton, Harold .	90 Spencer Road, Sheffield	Sir R. A. Hadfield, I. B. Milne, T. G. Elliot.

The SECRETARY then read the following Report of Council for the year 1916:

REPORT OF COUNCIL.

The Council have pleasure in submitting to the members of the Iron and Steel Institute at this, the Forty-eighth Annual General Meeting, their Annual Report of the progress of the work of the Institute for the year 1916.

Presidency of the Institute.

At the Annual Meeting on May 4 Sir William Beardmore, Bart., entered into office as President in succession to the late Dr. Adolphe Greiner. During the time that elapsed between Dr. Greiner's death in November 1915 and the Annual Meeting of 1916, Dr. Arthur Cooper continued to fulfil the duties of Acting-President, a service which he performed from the time that all direct communication with Mr. Greiner had been interrupted in August 1914.

Honorary Treasurership.

Mr. Illtyd Williams has been elected Honorary Treasurer of the Institute, in succession to Sir William Beardmore, who formerly filled that office.

Roll of the Institute.

There were forty-nine new members elected during the year, and the total membership of the Institute on December 31, 1916, was—

Patron	1
Honorary Members	6
Life Members	64
Ordinary Members	1801
Total	1872

In accordance with the powers conferred on the Council under the new by-law confirmed at the last Annual Meeting, the names of members of enemy nationality still remaining on the list at the end of 1915 (86 in all) have been struck off the roll of the Institute, the total number at the beginning of the war having been 107. There have been 35 resignations of members during the twelve months ended December 31, 1916, and the names of 16 members have been removed from the list owing to the non-payment of subscriptions.

The Institute has had further to record the loss by death of the following forty-two members, among whom are several who were prominently associated with the work of the Institute. The list also contains the names of five members who have lost their lives in the service of the country:

Baird, Matthew B. (Hamilton, N.B.)	December 16.
Beesley, Herbert (Sheffield)	February.
Bloomer, Clifford Edward (Halesowen)	June 4.
Burnyeat, William John Dalzell (Whitehaven, Cumberland)	May 8.
Carson, William (Chester)	February 5.
Colver, Robert (Sheffield)	December 2.
Colville, Archibald (Motherwell)	December 11.
Colville, David (Motherwell)	October 16.
Cooper, Ebenezer Elias (Brierley Hill)	October 20.
Cooper, G. Stanley (Cleckheaton)	December 15.
Courtman, Reuben S. (London)	March 24.
Davies, John William (Newcastle-on-Tyne)	August 8.
Dodgson, Thomas Edward (Rotherham)	July 24.
*Donaldson, Sir Hay Frederick, K.C.B. (London)	June 5.
Drummond, T. J. (Montreal)	August 6.
Hailstone, George (Smethwick)	February 13.
Hanning, William (Paris)	June 25.
Hoskins, H. G. (N.S.W., Australia)	October 30.
Hunter, David (Leeds)	August.
Ingleby, Joseph (Manchester)	July.
Jaques, *Captain* W. H. (High Barnet, Herts.)	November 28
Kirchhoff, Charles (New York)	July 22.
†Labrousse, Charles Jacques (Paris)	October 7.
‡Lloyd, Francis Henry (Lichfield)	January 5.
McCosh, Andrew Kirkwood (Coatbridge)	January 23.
§McCourt, Cyril Douglas (London)	October 8.
McNeill, Bedford (London)	September 19.
Oakes, Gerard R. (Alfreton)	June.
Panton, W. H. (Worthing)	December 10.
Pilkington, Herbert (Chesterfield)	November 24.
Price-Williams, R. (Bournemouth)	September 19.

* Lost in the wreck of H.M.S. *Hampshire*, June 5, 1916.
† Killed in action, October 7, 1916.
‡ Original Member.
§ Killed in action in France.

*Richards, Edwin (Nantyderry)	January 11.
Ritchie, James (Middlesbrough)	July 2.
†Robertson, Leslie Stephen (London) . . .	June 5.
Robson, Neil (Glasgow)	July 25.
*Spencer, John (Coatbridge)	May 24.
Stevens, John (Birmingham)	March 15.
Stewart, Wesley Hackworth (Middlesbrough) .	August 31.
Suppes, Max M. (Lorrain, Ohio, U.S.A.) . .	March 27.
Theys, Alfred (Brussels).	March 5.
Tomkins, Henry (Stockton-on-Tees). . .	May 18.
Wood, Edward Malcolm (London) . . .	July 27.

The deaths of the five following members occurred in 1915, but were not noted in the Council Report for that year:

Bettini, Raffaeli (Rome)	September 24.
Fraser, Graham (New Glasgow, Nova Scotia) .	December 25.
‡ Lusk, *Captain* James (Motherwell) . .	December 29.
Reuterskjöld, Arvid (Hellefors, Sweden) . .	June 27.
Wotherspoon, John (Cambuslang) . . .	December 17.

Honours conferred upon Members of the Institute.

The Council have had occasion to offer their congratulations to several members who have received new appointments or have had honours conferred upon them.

The Duke of Devonshire, K.G., Past-President, has been appointed Governor-General and Commander-in-Chief of the Dominion of Canada.

Lieut.-Colonel Maurice L. Bell has been created a Companion of the Order of St. Michael and St. George, and Sir George T. Beilby, F.R.S., has received the honour of knighthood. The Order of the Companion of the Bath has been conferred upon Captain Riall Sankey, and on Colonel N. T. Belaiew of the Imperial Russian Artillery.

Colonel W. F. Cheesewright and Major M. G. Christie have both been honoured with the D.S.O., Captain Lusk (died of wounds in France) has received the Cross of the Legion of Honour, Lieutenant Lucien Arbel (Lieutenant of Artillery in the French Army) the "Croix de Guerre avec Palme" for distinguished conduct in the field, and Captain J. Labrousse (killed in action) the "Croix de Guerre."

* Original Member.
† Lost in the wreck of H.M.S. *Hampshire*, June 5, 1916.
‡ Died of wounds in France.

In addition to the above upwards of one hundred members hold appointments under the Ministry of Munitions of War.

A list of the members on active service with the Forces of the Allied countries is given at the end of this report.

FINANCE.

The statement of accounts for the year 1916 has been verified by the Auditors of the Institute, and is included in the usual way in the Report of the Honorary Treasurer. The accounts show that the total receipts of the Institute for the year, excluding the income of the Carnegie Research Fund, were £4767, and the expenditure was £4208. The excess of income over expenditure on the General Account is thus £559. The corresponding figures for recent years are as follows:

	Income.	Expenditure.
	£	£
1913	5580	5344
1914	5310	4701
1915	4816	4275

The receipts on account of the Carnegie Research Fund were £898 and the expenditure was £575, the surplus of income over expenditure being £323.

MEETINGS.

The Annual Meeting took place on May 4 and 5, 1916, at the Institution of Civil Engineers.

The Autumn Meeting was also held, by kind permission, in the rooms of the same Institution on September 21 and 22.

At the Annual Meeting Dr. Arthur Cooper opened the proceedings, and after the despatch of the usual formal business he inducted into the Chair the new President, Sir William Beardmore, Bart., who then delivered his Inaugural Address. Besides this address eighteen papers were contributed to the proceedings of the Institute at its two meetings, all of which have been printed in the Journal, together with the discussion and correspondence thereon. The titles of these papers are as follows:

1. "The Theory of the Corrosion of Steel." By L. AITCHISON, M.Met., B.Sc. Lond. (Sheffield).
2. "Notes on the Relations between the Cutting Efficiencies of Tool Steels and their Brinell or Scleroscope Hardness." By J. O. ARNOLD, D.Met., F.R.S. (Sheffield University).
3. "A New Thermo-Electric Method of Studying Allotropic Changes in Iron or other Metals." By C. BENEDICKS, Ph.D. (Stockholm).

4. "Some Properties of Ingots." By A. W. and H. Brearley (Sheffield).
5. "Thermo-Electric Measurement of the Critical Ranges of Pure Iron." By George K. Burgess, Sc.D., and H. Scott (Bureau of Standards, Washington).
6. "The Influence of Heat Treatment on the Thermo-Electric Properties and Specific Resistance of Carbon Steels." By Professor E. D. Campbell (Ann Arbor, Mich.).
7. "Initial Temperature and Critical Cooling Velocities of a Chromium Steel." By C. A. Edwards, D.Sc. (Manchester University).
8. "The Influence of Carbon and Manganese upon the Corrosion of Iron and Steel." By Sir Robert Hadfield, Bart., D.Met., F.R.S., and J. N. Friend, D.Sc., Ph.D. (London).
9. "The Transformations of Special Steels at High Temperatures." By K. Honda (Sendai), K. Tawara, and H. Takagi.
10. "Notes on Pearlite." By H. M. Howe, LL.D., Sc.D., and A. G. Levy (New York).
11. "Steel Ingot Defects." By J. N. Kilby (Sheffield).
12. "Manganese Ores of the Bukowina." By Herbert K. Scott (London).
13. "Influence of some Elements on the Mechanical Properties of Steel." By J. E. Stead, D.Sc., D.Met., F.R.S. (Middlesbrough).
14. "Notes on Nickel Steel Scale and on the Reduction of Solid Nickel and Copper Oxides by Solid Iron." By J. E. Stead, D.Sc., D.Met., F.R.S. (Middlesbrough).
15. "Notes on the Effect of Blast-furnace Gases on Wrought Iron." By J. E. Stead, D.Sc., D.Met., F.R.S. (Middlesbrough).
16. "A Few Experiments on the Hardness Testing of Mild Steel." By W. N. Thomas, B.Sc. (Birmingham).
17. "Surface Tension Effects in the Intercrystalline Cement in Metals and the Elastic Limit." By F. C. Thompson, M.Met., B.Sc. (Sheffield University).
18. "The Use of Meteoric Iron by Primitive Man." By G. F. Zimmer, A.M.Inst.C.E. (London).

Appointment of Technical Committees.

The question of the more efficient organisation of the work of the Institute has been under the careful consideration of the Council during the past year, and it has been thought that the effective co-operation of the members in the work of the Institute might be increased by the appointment of a certain number of Technical Committees to advise as to subjects of practical interest to the iron and steel industries, on which the Council can organise discussions at General Meetings, or which may require investigation and research. Five such Committees have been formed, their names and constitution being as follows:—

1. *Ores, Fuel, Refractories.*

Mr. W. H. Hewlett.
Mr. R. Armitage.
Dr. W. A. Bone.
Mr. A. Hutchinson.
Mr. Cosmo Johns.
Mr. Myles Kennedy.
Professor H. Louis.
Mr. W. Thorneycroft.

2. *Blast-Furnaces.*

Sir John Randles, M.P.
Mr. A. Anderson.
Mr. P. Cooper.
Mr. A. Crooke.
Mr. L. F. Gjers.
Mr. J. H. Harrison.
Mr. W. Hawdon.
Mr. G. Hedley.
Mr. W. S. Hill.
Mr. A. Hutchinson.
Mr. G. Jones.
Mr. A. Lennox Leigh.
Mr. H. Preston.
Mr. A. K. Reese.
Mr. T. B. Rogerson.

3. *Steel and its Mechanical Treatment and Ferro Alloys.*

Mr. C. J. Bagley.
Mr. A. Lamberton.
Mr. M. Mannaberg.
Mr. Vernon Abbot.
Mr. W. F. Beardshaw.
Mr. H. Brearley.
Mr. P. B. Brown.
Mr. D. F. Campbell.
Mr. A. J. Capron.
Mr. J. J. Cohade (Le Creusot).
Mr. F. W. Cooper.
Mr. T. Crosby.
Mr. E. Crowe.
Mr. P. N. Cunningham.
Mr. J. H. S. Dickenson.
Mr. R. Gray.
Mr. E. C. Greig.
Mr. D. M. Maclay.
Mr. J. MacFarlane.
Mr. G. Ritchie.
Mr. E. H. Saniter.
Mr. W. Simons.
Mr. M. L. Simpson.
Mr. C. P. Williams.
Mr. J. Williams.

4. *Iron and Steel Foundry Practice.*

Sir Robert A. Hadfield.
Mr. E. Adamson.
Mr. G. N. Cook.
Mr. W. J. Dawson.
Mr. J. E. Fletcher.
Dr. W. H. Hatfield.
Mr. W. Shaw.
Mr. H. B. Toy.
Professor T. Turner
Mr. S. W. Williamson.
Mr. H. J. Yates.

5. *Metallography, Chemistry, and Physics.*

Dr. J. E. Stead.
Dr. J. O. Arnold.
Mr. H. H. Ashdown.
Dr. T. Baker.
Mr. C. O. Bannister.
Dr. H. C. H. Carpenter.
Dr. C. H. Desch.
Mr. T. G. Elliot.
Dr. J. N. Friend.
Dr. W. H. Hatfield.
Dr. H. M. Howe.
Mr. E. W. Jackson.
Mr. E. F. Law.
Mr. A. McCance.
Mr. J. McWhirter.
Major W. H. Merrett.
Mr. I. B. Milne.
Mr. D. J. Pinkerton.
Mr. C. H. Ridsdale.
Dr. W. Rosenhain.
Mr. D. Sillars.

Four of these Committees have held a first meeting since the beginning of the present year, and plans are in progress for arranging suitable programmes for future General Meetings.

Bessemer Medal.

The Bessemer Gold Medal for the year 1916 was presented to Mr. Frank W. Harbord, Assoc.R.S.M., F.I.C., in recognition of his eminent services in the advancement of the metallurgy of iron and steel. A full account of the presentation is given in the Journal, No. I. for 1916, p. 20.

Formation of a Class of Associates.

By resolution of Council a new class of members, to be known as Associates, has been formed, particulars of which have already been published. The following are the conditions under which candidates can be admitted as Associates. The age of candidates shall not exceed twenty-four years, and they must have one or other of the following qualifications:

(a) Students of metallurgy taking courses at a University, University College, or Technical School;
(b) Pupils or apprentices to metallurgists or engineers, or in metallurgical or engineering works;
(c) Persons employed in some practical or scientific capacity in metallurgical or engineering works.

Application for admission as Associate must be made on a special form, to be obtained from the office of the Institute. No entrance fee is payable, and the annual subscription is one guinea, which will entitle Associates to attend all meetings and to receive the usual publications of the Institute, but they will be without the right to vote at General Meetings.

Associates, if qualified for membership under Bye-law 3, may, on application, be transferred by the Council to full membership. Associates on transfer to the Class of Members shall pay thereafter the usual annual subscription of two guineas, and shall be exempt from payment of an entrance fee. No Associate shall remain in the Class of Associates after the 31st day of December next following the day on which he attains the age of twenty-four.

Co-operation with Kindred Institutes.

The Council have also had in mind the possibility of establishing a closer relationship between the several Institutes in the country whose work is chiefly concerned with the advancement of the technology of iron and steel. With this purpose in view, an invitation has been extended to the Presidents of the following Institutes and Societies to attend during their term of office meetings of the Council of the Iron and Steel Institute, and to take part in its deliberations:

The Cleveland Institution of Engineers.
The Sheffield Society of Engineers and Metallurgists.
The Staffordshire Iron and Steel Institute.
The West of Scotland Iron and Steel Institute.

By this means a link between the several Institutes has been formed, and an opportunity is afforded for the consideration of any suggestions that may be conducive to the advantage of all or any of them.

Appointment of Corresponding Members in British Dominions.

In those British Dominions where a membership already exists the Council has decided to appoint one member to be " Corresponding

Member" for the Institute. His duties will consist in advising the Council of any arrangements which it might be to the advantage of the members living within his district to make, and in furthering the interests of the Institute in any way that may seem desirable.

The following have already kindly consented to act as Corresponding Members in the Dominions named:

Dr. Andrew McWilliam	for India.
Mr. J. P. Frankie	for the Commonwealth of Australia.
Dr. J. H. Plummer	for Canada.

Proposal for New Accommodation of the Institute.

Plans are under discussion for the accommodation of the Institute, jointly with several other scientific and technical Institutions, in one building, with a common Meeting-Room, Library, and Reading-Room. The Institutions of Mining and Metallurgy, and Mining Engineers, and the Institute of Metals have been approached, and the question of co-operating in securing joint accommodation with these Institutions is under consideration.

Education Reform.

In March 1916 a movement was set on foot by Sir E. Ray Lankester with the object of reforming the Civil Service Examinations by making some branch of Natural Science a compulsory subject. Sir Hugh Bell, having been consulted by Sir Ray Lankester as to the best method of organising the support of the leading industries of the country, advised him to enlist the co-operation of the principal scientific and technical institutions, and at Sir Hugh Bell's suggestion the Council lent its assistance to the movement by placing office accommodation in the Institute at Sir Ray Lankester's disposal, and by granting extra clerical assistance for the purpose of conducting his propaganda. A conference was organised at the rooms of the Linnean Society on May 3, which was very largely attended, the Institute being represented officially by Sir William Beardmore, Sir Hugh Bell, and Sir Robert Hadfield.

The chair was taken by Lord Rayleigh, and the speakers included Lord Montagu of Beaulieu, the Right Hon. F. Huth Jackson, Dr. Macan (Master of University College), Sir Hugh Bell, Sir H. H. Johnston, Mr. H. G. Wells, and others. Resolutions were carried authorising the Committee to take such steps as they might consider appropriate in order to urge upon His Majesty's Government the necessity of making the natural sciences an integral part of the educational course in all the great schools of this country.

Committee of the Privy Council for Scientific and Industrial Research.

A grant of £100 was offered to the Institute by the Committee for Scientific and Industrial Research to meet the cost of preparing for the Committee a statistical survey of the supply of raw material (exclusive of fuel) for use in the iron and steel industries. The offer having been accepted by the Council, a report dealing with the iron ore resources of the United Kingdom and the British Dominions, and with the principal iron ore resources of other countries, as far as information was available, was compiled and submitted to the Research Council in December. A further section of the report referred to the occurrence and production of the ores of other metals used in the industry, such as chromium, cobalt, manganese, molybdenum, nickel, tungsten, titanium, vanadium, and zirconium.

Publications.

During the past year the usual two cloth-bound volumes of the Journal of the Institute have been published, together with the List of Members. The seventh volume of the Carnegie Scholarship Memoirs, containing the reports on research work carried out with the aid of grants from the Carnegie Research Fund during 1914 and 1915, has also been issued. These publications contain altogether 1377 pages of text, and 76 plates, in addition to numerous illustrations in the text.

Besides the papers read at the Spring and Autumn Meetings and the discussions and correspondence to which they gave rise, abstracts and references to all the principal articles and memoirs relating to the iron and steel industries published in the Transactions of kindred Institutions and Societies at home and abroad, and in the technical press of this and other countries, have been compiled and published in the Notes on the Progress of Home and Foreign Iron and Steel Industries. In the collection and compilation of these abstracts over three hundred different periodicals have been systematically studied, and reference to the information contained therein has thus been facilitated. Most of the original sources of information are filed in the Institute Library, where members can consult them at their convenience.

Library.

The attendances at the Reading-Room of the Institute during the past year have been more numerous than in previous years, and the number of readers who have consulted the Library has increased

considerably. Many members have also availed themselves of the permission granted by the Council four years ago of borrowing books under certain conditions, a privilege which appears to be greatly appreciated. The number of volumes lent out during the year has been 105.

Numerous additions have also been made to the Library within the past twelve months. The donations include: "The Metallography of Steel and Cast Iron," by Dr. H. M. Howe; "The Metallography and Heat Treatment of Iron and Steel" (second edition), by Professor A. Sauveur; "The Works of D. Tschernoff," by Professor D. Tschernoff; "The Heat Treatment of Tool Steel," by H. Brearley, and "The Value of Science in the Smithy and Forge," by W. H. Cathcart. All these have been generously presented by their respective authors.

Among the books which have been purchased are: "Steel and its Heat Treatment," by D. K. Bullens; "The Rare Earth Industry," by S. J. Johnstone; "Coal, Tar, and Ammonia" (5th edition, in 3 vols.), by G. Lunge, and "The Physical and Chemical Properties of Steel," by C. A. Edwards.

A complete list of the additions to the Library is given in the last number of the Journal.

Andrew Carnegie Research Fund.

With regard to the administration of the Carnegie Fund the Council have found that, owing to the restriction imposed on the age of candidates, applications for grants for research work have not been coming forward as freely as usual since the beginning of the war. They therefore communicated with Mr. Carnegie on the subject, who was good enough to reply that he would be pleased to leave the matter to the judgment of those in whose hands the administration of the Fund had been placed, and that he would be satisfied with whatever action the Council might take in the matter needing consideration. The Council thereupon decided to suspend the age limit of thirty-five for the present, and to modify the scheme under which applications were invited as follows:

'The Council of the Iron and Steel Institute is prepared to make from the Research Fund, founded by Mr. Andrew Carnegie, Past-President, a limited number of grants in aid of research work on problems of practical importance relating to the metallurgy of iron and steel and allied subjects. Applications may be sent in on a special form before the end of March to the Secretary of the Institute.

Directors of Private and Public Laboratories, Principals of Metal-

lurgical Training Establishments, and Managers of Iron and Steel Works, who desire to promote research work on some problem connected with the metallurgy of iron and steel or an allied subject, are invited to submit proposals for a grant for the purpose of such an investigation to be carried out by some qualified person nominated by themselves and working under their supervision.

Independent investigators are also invited to apply for a grant for similar purposes, provided that they satisfy the Council that they are properly qualified to carry out the research work which they propose to perform.

In considering the allocation of grants the Council will be guided by the nature of the subjects proposed for investigation, and will give preference to those which, in their judgment, appear to be of the most practical advantage to the iron and steel and allied industries.

Various applications for grants under the modified scheme were received in 1916 and awards were made to the following:

Mr. G. R. Bolsover (Sheffield), £50 for an investigation of the slag, oxygen, and nitrogen contents of crucible, acid open-hearth, and acid Bessemer steels.

Mr. J. H. Whiteley (Middlesbrough), £50 for an investigation on the relation between the carbide in steel and the Eggertz colour method.

Mr. W. C. Hancock (London), £100 for an investigation on refractory material, with special reference to materials for coke-oven and furnace construction.

Messrs. J. L. Haughton and D. Hanson (National Physical Laboratory), £100 for a joint research on the iron-phosphorus system.

Mr. F. Ibbotson (Sheffield), £50 for an investigation on the constitution of high-speed steel.

Mr. P. Saldau (Petrograd), £50 for an investigation on special steels.

Dealings with the Fund.

With reference to the Fund itself as presented by Mr. Carnegie it will be remembered that the bulk of this consisted of American Bonds, namely, $64,000 Pittsburg, Bessemer, and Lake Erie R.R. 5 per cent. Debenture Bonds and $25,000 United States Steel Corporation Bonds. Early in the year the Government notified its desire to take over American securities held in this country, and accordingly the Council requested the Hon. Treasurer to dispose of the above-mentioned bonds and to reinvest the proceeds of the sale in some suitable security yielding an approximately equivalent income. The amount realised by the two lots of bonds was £18,980, and the Hon. Treasurer, in con-

sultation with the President, has now completed the reinvestment of the whole of this sum on behalf of the Institute by the purchase of British Railway Stocks and India 3 and $3\frac{1}{2}$ per cent. Stock. The statement of accounts shows exactly the amount of each kind of stock which has been bought.

Appointment of Representatives.

The President continues to represent the Institute on the General Committee of the Royal Society for administering the Government Grant for Scientific Investigations. On the Board of the National Physical Laboratory the representatives of the Institute are Sir Hugh Bell, Bart., and Mr. W. H. Ellis. Sir Hugh Bell has also continued to act as representative on the Board of Governors of the Imperial College of Science and Technology. On the Engineering Standards Committee the Institute is represented by Mr. Arthur Cooper, Mr. George Ainsworth, and Mr. Illtyd Williams, while Mr. Charles Dorman and Mr. R. E. E. Spencer continue respectively to serve on the Engineering Standards Sub-Committee for the Standardisation of Galvanised Sheets, and the Sub-Committee for Special Steels for Motor Car Construction. Sir William Beardmore, Bart., and Mr. George Ainsworth have continued to act as representatives of the Institute on the Technical Committee of Lloyd's Register of British and Foreign Shipping. Sir William Beardmore has been nominated by the Council on the Institution of Automobile Engineers Committee on Special Steels for Automobile and Aircrafts Construction. Sir William Beardmore and Sir Hugh Bell have been appointed representatives of the Institute on the Board of Scientific Societies of the Royal Society. Dr. J. E. Stead, F.R.S., represents the Institute on the Advisory Committee of the Royal School of Mines. Sir Robert Hadfield acts as representative of the Institute on the Court of Sheffield University, and continues to serve on the Home Consulting Committee of Hong-Kong University. Mr. W. Peter Rylands represents the Institute on the Court of Liverpool University.

Changes on the Council.

The election of Sir William Beardmore as the new President, and of Mr. Illtyd Williams as Honorary Treasurer, has been already referred to. The further changes in the list of the Council that have occurred during the past year are as follows:

Mr. P. C. Gilchrist and Dr. H. M. Howe have been elected Honorary

Vice-Presidents. To the great regret of the Council, Mr. J. H. Darby has found himself obliged, for reasons of health, to retire from the Council, and there have been elected as new Members of Council: Sir Charles Allen, Dr. J. O. Arnold, F.R.S., and Mr. F. W. Harbord.

The Vice-Presidents and Members of Council who, in accordance with Bye-law 10, are due to retire in May, and whose names were announced at the last General Meeting, are: *Vice-Presidents*—Mr. W. H. Hewlett, Mr. C. J. Bagley, and Mr. W. H. Ellis. *Members of Council*—Sir Gilbert H. Claughton, Bart., Lord Airedale, Mr. W. Peter Rylands, Mr. Frederick Mills, and Professor H. Le Chatelier. No other members having been nominated up to within one month previous to the Annual Meetings of 1917, the retiring members are presented for re-election.

Members on Service in the Forces of the Allied Nations.

The following is a list of the names of those members who are known to have undertaken active service since the beginning of the war; it has been endeavoured to make it as complete as possible, but there are probably members, subjects of the other allied countries, concerning whom no note has been received. In those cases where no alteration in rank has been notified since 1915 the same rank is given as in the original list published in Journal No. I., 1915.

Name.	Town.	Rank.
Ablett, C. Antony	London	Lieutenant
Allen, Cecil	Sheffield	Lieut.-Colonel (T.F.)
Allen, Sir Charles, V.D.	Sheffield	Colonel (T.F.)
Anderson, J. A.	Newcastle-on-Tyne	
[1] **Arbel, Lucien**	Paris	Lieutenant
Armitage, William J.	Sheffield	Major
Armstrong, Percy T.	London	Lieutenant
Aspinall, John A. F.	Liverpool	Lieut.-Colonel (T.F.)
Atkinson, H. Milne	Manchester	Captain
Bagley, C. H. F.	Stockton-on-Tees	2nd Lieutenant
Bagnall-Wild, R. K.	Farnborough, Hants.	Lieut.-Colonel
Balzarotti, G. P.	Milan	Lieutenant
Baraduc-Muller, Louis	Paris	Captain
Bayley, H. Dennis	Nottingham	(Brit. Red Cross)
Belaiew, N. T., C.B.	Petrograd	Colonel
Bell, Maurice L., C.M.G., V.D.	Northallerton	Lieut.-Colonel
Bengough, G. D.	Liverpool	Captain
Bowden, Geo. Harland, M.P.	St. Albans, Herts.	Lieut.-Colonel

[1] Awarded "La Croix de Guerre avec Palme."

NAME.	TOWN.	RANK.
Boyd, Archibald J.	London	Lieutenant (T.F.)
Breuil, Pierre	Nogent-sur-Marne, France	2nd Lieutenant of Artillery
Burnyeat, R. W.	Workington	Captain (T.F.)
Butler, A. I. R.	Newport, Mon.	Major (Commanding)
Butler, Basil H.	Leeds	Captain
Butler, Hubert Oswald	Newport, Mon.	Captain
Carnegie, David	London	Staff Lieut.-Colonel
[1] **Cheesewright, William F.**	London	Lieut.-Colonel (T.F.)
Cleland, W. L.	Newcastle, N.S.W.	
[1]**Christie, Malcolm Grahame**	Leeds	Major
Clough, T. Carter	Sheffield	Major
Coe, Henry I.	Swansea	Lieutenant
Colver, Dr. E. de Wykersley Swyft	Sheffield	Lieutenant
Connolly, J.	Birmingham	Lieutenant
Coombe, L. Jackson	Sheffield	Major
Cooper, Douglas Ludlow	Middlesbrough	British Red Cross
Cowan, J. H.	London	Colonel
Crompton, Rookes, E. B.	London	Colonel (T.F.)
Crosland, J. C. H.	Mobberley, Cheshire	Lieut.-Colonel
[2] **Darwin, Erasmus**	Middlesbrough	2nd Lieutenant
Davie, Thomas, Jun.	Coatbridge, N.B.	Lieutenant
Davies, D. Sidney	Gateshead-on-Tyne	
Davis, Frank P.	Nottingham	Captain
Dick, Robert D.	Redcar, Yorks.	Private
Dore, Alan S. W.	Stourport	Major (T.F.)
Dorman, Arthur	Yarm, Yorks.	Captain
Ellison, W. R.	Sheffield	Captain
Else, Stanley Cyril	Sheffield	Lieutenant
Fernihough, H.	Sketty, Glam	Lieutenant
Field, G. K.	London	Lieutenant
Friend, J. N.	London	Lieutenant
Gray, William Carlaw	Glasgow	2nd Lieutenant
Gwynne, R. H. B.	Bristol	Lieutenant
Hammond, Joseph	Wollaston, Stourbridge	Captain
Hedley, George	Middlesbrough	Captain
Henderson, E. B. Butler	Stafford	Captain
Hopkinson, Allen H.	Huddersfield	Recruiting Officer
Hopkinson, Prof. B., F.R.S.	Cambridge	Major (Camb. Univ. O.T.C.).
Horne, James W.	London	Private
Ingle-Finch, George	London	2nd Lieutenant
Jackson, G. M.	Chesterfield	Brigadier Commander
Jackson, J. Arthur	Calderbridge	Major (T.F.)
Jenkins, Robert William	Rotherham	Captain (T.F.)
Jobson, R. H. T.	Newcastle-on-Tyne	Major
Johnson, Herbert Alfred	Manchester	Lieut.-Colonel (Commanding)
Johnson, Walter L.	Middlesbrough	Lieut.-Colonel
Kitson, The Hon. R. D.	Leeds	Lieutenant
Lees, John	Birmingham	Major
Lewis, R. A.	Ebbw Vale, Mon.	Captain

[1] Awarded the D.S.O.
[2] Killed in action, April 23, 1915.

Name.	Town.	Rank.
[1] Labrousse, C. J.	Paris	Captain (Commanding)
Lloyd, D. C.	Tettenhall.	Captain (T.F.)
Lloyd, D. W. Edison	Merthyr Tydfil	Engineer
Longden, A. H.	Stanton-by-Dale	Captain
[2] Lusk, J.	Motherwell	Captain and Adjutant
McBean, Alex., V.D.	Wolverhampton	Colonel
[3] M'Court, Cyril D.	London	2nd Lieutenant
McNeill, Hugh Colley	Rantek, India	Farrier Sergeant-Major
McWilliam, Dr. A.	Kalimati, B.N.R.	Captain (Commanding)
[4] Marsh, John L.	Sheffield	Captain
Merrett, Prof. W. H.	Wallington, Surrey	Major
Monks, Austen J.	Appleton, Cheshire	Captain
Monks, F. Remund	Appleton, Cheshire	Major (Commanding)
Morgan, K. P. Vaughan	London	Captain
Morgan, Penry Vaughan	London	Lieutenant
Needham, Joseph G.	Manchester	Lieut.-Colonel (T.F.)
[5] Nicou, Paul-René	Paris	Lieutenant
Pennymore, P. G., D.S.O.	Brierley Hill	Lieut.-Colonel
Petherick, John	Consett	Major
Phillips, George, J.P.	London	Staff Major-General
Pollen, Francis H.	London	Commander
Pollen, Stephen H.	London	Lieut.-Colonel
Randall, Charles R. J.	Barrow-in-Furness	Eng. Lieut.-Commander R.N., Squadron Commander (E.) R.N.A.S.
Rees, W. D.	Swansea	Colonel (Commanding)
Reichwald, V. B.	London	Quartermaster-Sergeant
Richards, John A.	London	Engineer Commander
[6] Robin, Felix.	Paris	Lieutenant
Robinson, P. S.	Rochdale	2nd Lieutenant
[7] Rogerson, W. E.	Darlington	Captain
Rosevere, G. R.	Wolverhampton	Lieutenant
Routledge, W.	South Bank, R.S.O.	Captain
Sankey, H. Riall	London	Staff Captain
Savage, Geoffrey H.	London	Lieutenant
Scott, Herbert K.	London	Lieutenant
Seaman, Wilfred A.	Sheffield	Major (Commanding) (T.F.)
Selby-Bigge, D. L.	Glasgow	Lieut.-Colonel
Sidney, Leicester P., Jun.	London	2nd Lieutenant
Skelton, J. H.	London	
Smith, J. Cruickshank	London	Lieutenant
Smith, Percy W.	Birmingham	Lieutenant
Somers, Frank	Birmingham	Captain
Speakman, E. M.	London	Lieutenant
Steel, H., Jun.	Sheffield	Captain
Stewart, V. Beardmore	Glasgow	Captain

[1] Awarded "La Croix de Guerre." Killed in action October 7, 1916.

[2] Awarded Cross of Legion of Honour. Died of wounds in France, December 29, 1915.

[3] Killed in action, October 8, 1916.

[4] Killed in action, October 16, 1915.

[5] Prisoner of War in Germany.

[6] Killed in action.

[7] Died at Bullswater Camp, Woking, November 13, 1914.

Name.	Town.	Rank.
Storey, Charles B. C.	Ruabon, Denbighshire	Lieutenant
Struthers, J. G.	London	Flight Sub-Lieutenant
Taylor, H. J. C.	Sheffield	
Thomas, C. W.	Pedmore, nr. Stourbridge	Major
Thomlinson, W.	Seaton Carew	Lieut.-Colonel
Tofts, C. F.	Jamalpur, India	Lieutenant
Trubshaw, H. E.	Llanelly	Major
Wadham, Walter F. A.	Dalton-in-Furness	Lieut.-Colonel (Commdg.)
Watson, Henry A.	York	Major (T.F.)
Whitehead, Lionel D.	Tredegar, Mon.	Captain (T.F.)
Wraith, H. O.	Twickenham, Middlesex	Lieutenant
Wright, W. Charles	London	Colonel
Wyman, R.	Newport, Mon.	Captain (T.F.)

The following members of the Institute Staff are also serving in the Army:

Arthur Dowd	Rifleman (K.R.R.C.)
Richard Elsdon	Lance-Corporal (R. Inniskilling Fusiliers).

STATEMENT OF ACCOUNTS.

The HONORARY TREASURER (Mr. Illtyd Williams), in submitting the Accounts and Balance Sheet for the year 1916, said they were put forward in a somewhat different form from that in which they had been previously presented. The Carnegie Research Fund Account had been separated from the General Income and Expenditure Account of the Institute, and the whole of the invested funds forming the Capital Account of the Institute, and the investments forming the Carnegie Fund, had been brought into the balance sheet for the first time. Dealing with the Institute General Account, the income had been £4767, and the expenditure £4208. In the Report of Council the comparative figures for the three years, 1913, 1914, and 1915, were shown. It would be seen that there had been a steady decline in the income since 1913, the heaviest falling off occurring in the year 1915. That the receipts diminished in that year was not surprising, as it was the first year in which the reduction of income, due to the war, took full effect. Altogether 107 names of enemy aliens had disappeared from the list of members. Moreover, since the beginning of the war, the Institute had lost touch with 33 Belgian members, representing about 90 per cent. of the membership of Belgium, and with 9 French members. Although the names of those members had of course been retained in the list as active members, no fees had been received from them. Moreover, 7 of the British members had laid down their lives for the country. Owing to those and other contributing causes, there had been a total reduction in the membership of 230 between December 31, 1913, and December 31, 1916, which fully accounted for the reduced income. On the other hand, economies in expenditure had been effected, mainly due to the reduced cost of the Autumn Meetings and to the lessened bulk of the publications, so that each year there had still been a surplus to carry forward. The income in 1916 from subscriptions was the lowest since 1903, and that was quite a serious matter, especially in view of the fact that the activities of the Institute were increasing, and were certain to increase still more in the future if it was to continue properly to fulfil the functions for which

it existed. Happily there was every indication of an early recovery of some of the losses in membership, and the Institute might consider itself as past the lowest point of the curve. He desired, however, to urge upon all connected with the iron and steel trades the advisability of seeing that as many of their staff as possible, particularly the younger, became members, and that they should give them facilities, as far as possible, for attending the meetings, as he believed that they would be amply repaid by the increased knowledge which those members would acquire. The accounts otherwise presented no unusual features; but in connection with the Carnegie Research Fund, the American bonds, which formed the bulk of the invested funds, had been sold and the proceeds reinvested in British securities. The gross income from the new investments would be slightly larger than before. In 1916 the Council purchased £712 1s. 3d. 4½ per Cent. War Loan Stock, at a cost of £698 18s. 8d. Those dealings related only to 1916, the year covered by the present report; but so far as the current year was concerned, perhaps he might be allowed to anticipate matters by saying that when the new War Loan was floated early this year, the above amount was converted into £749 10s. 8d. new 5 per Cent. War Loan Stock, and the Council invested a further sum of £2137 10s. 0d. in the new War Loan by taking up Stock to the value of £2250, the total holding of the Institute now being £2999 10s. 8d., which would be made up to the round £3000 so soon as the allotment of the fraction of Stock to which the Institute was entitled was received.

THE IRON AND STEEL INSTITUTE.

BALANCE SHEET, DECEMBER 31, 1916.

LIABILITIES.

To Sundry Creditors:—			
„ Journal Printing and Publishing		£574 15 10	
„ Journal Postages...		45 1 9	
„ Library Books and Binding		2 1 3	
„ Salaries Account		50 0 0	
„ Office Rent, &c.		179 4 7	
„ Printing and Stationery		97 19 1	
„ Sundry Payments		0 9 6	
„ Board of Education, balance of grant unexpended		66 9 0	
			£1,016 1 0
„ Subcriptions in Advance			30 9 0
„ Carnegie Scholarship Fund:— Sundry Creditors—			
Grants due 1916 ...	£ 62 10 0		
Printing, &c. ...	266 2 10		
		£ 328 12 10	
„ Amount of Funds represented by investments (*per contra*)		21,241 5 6	
„ Accumulated Surplus Income:—			
As at 1st January 1916	£768 7 11		
Add Excess of Income over Expenditure to Dec. 31, 1916	322 18 5		
		1,091 6 4	
			22,661 4 8
„ The Iron and Steel Institute Capital Account:—			
Investments as at 1st January 1916 at Cost		£14,406 14 0	
Add Amount invested during the Year		500 0 0	
Investments (*per contra*) at date ...		14,906 14 0	
„ Accumulated Surplus Income:—			
As at 1st January 1916 ...	£2,228 12 2		
Less Amount invested during year	500 0 0		
	£1,728 12 2		
Add Excess of Income over Expenditure for the year	559 9 5		
		2,288 1 7	
			£17,194 15 7
			£40,902 10 3

ASSETS.

By Subscriptions in arrear, since received			£ 71 8 0
„ Interest on Investments accrued due at 31st December 1916, since received			220 8 8
„ Journal Sales, since received			102 10 6
„ Investments on account of Life Compositions, at cost, as per schedule attached			2,264 17 4
„ Invested Funds of the Institute, at cost, as per schedule attached (*per contra*)			14,906 14 0
„ Telephone Deposit			1 0 0
„ Cash at Bankers and in Hand:—			
On Deposit Account		£1,300 0 0	
On Current Account		152 3 10	
		£1,452 3 10	
Secretary's Balance:—			
At Bank	£335 16 6		
In Hand	1 16 8		
		337 13 2	
		£1,789 17 0	
Less Carnegie Fund included therein		1,115 9 11	
			674 7 1
„ Carnegie Scholarship Fund:—			
Investments as per Schedule attached, at cost (*per contra*)		£21,241 5 6	
Interest on Investments accrued due at 31st December 1916, since received...		304 9 3	
„ Cash as above		1,115 9 11	
			22,661 4 8
			£40,902 10 3

ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1916.

INCOME.

To Entrance Fees		£ 100 16 0
„ Annual Subscriptions		3720 3 0
„ Life Compositions		31 10 0
„ Journal Sales		277 11 1
„ Interest on Investments, *Less* Tax	£483 8 6	
„ Income Tax recovered to 31st March 1916 ...	80 7 2	
		563 15 8
„ Bessemer Medal Fund :—		
Interest on Investment, *Less* Tax	£13 2 4	
Income Tax recovered to 31st March 1916	2 2 8	
		15 5 0
„ Interest on Deposit		57 8 1
„ Sundry Receipts		0 19 8
		£4767 8 6

EXPENDITURE.

By Salaries (including Overtime)		£1751 15 10
„ Office rent, Cleaning, &c.		707 3 9
„ Library Books and Binding		72 1 6
„ Office Furniture		1 17 0
„ Autumn Meeting		30 10 2
„ Annual Meeting		29 0 10
„ Journal Publishing Expenses :—		
Printing, &c.	£938 3 11	
Abstracts	72 18 6	
Translations	1 16 8	
Postage	83 0 0	
		1095 19 1
„ Stationery and Printing (including copies of Papers) ...		302 15 3
„ Postage and Receipt Stamps		82 15 10
„ Insurance		9 11 4
„ Bessemer Medal Fund Expenditure :—		
Gold Medal		15 5 0
„ Telephone		21 10 0
„ Travelling Expenses		13 2 0
„ Auditor's Fee		21 0 0
„ Sundry Payments...		53 11 6
„ Balance, being excess of Income over Expenditure ...		559 9 5
		£4767 8 6

ANDREW CARNEGIE RESEARCH SCHOLARSHIP FUND.

ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1916.

To Interest on Investments, *Less* Tax :—		
Pittsburgh, Bessemer and Lake Erie Railroad 5 per cent. Gold Debenture Bonds. (Sold June 1916)	£249 5 4	
United States Steel Corporation 5 per cent. Gold Debenture Bonds. (Sold July 1916)...	97 6 7	
£2250 Newcastle-upon-Tyne Electric Supply 4½ per cent. Consolidated First Mortgage Debenture Stock	78 11 10	
£2600 Great Central Railway 4½ per cent. Debenture Stock	43 17 6	
£3000 Great Central Railway 3½ per cent. Second Debenture Stock	39 7 6	
£5000 Great Northern Railway 3 per cent. Debenture Stock	56 5 0	
£5000 Great Eastern Railway 4 per cent. Debenture Stock	75 0 0	
£2000 Caledonian Railway 4 per cent. Debenture Stock	30 0 0	
£2000 North British Railway 3 per cent. Debenture Stock	22 10 0	
£2000 Taff Vale Railway 3 per cent. Debenture Stock	22 10 0	
£2300 India 3½ per cent. Stock	15 1 11	
£2560 4s. India 3 per cent. Stock	14 8 0	
	£744 3 8	
„ Income Tax recovered to 31st March 1916 ...	153 15 11	
		£897 19 7
		£897 19 7

By Expenditure, viz. :—		
Scholarships	£350 0 0	
Printing Memoirs	223 3 10	
Postages of Memoirs	36 19 1	
Printing and Stationery	12 7 9	
Salary	52 0 0	
Sundry Payments	0 10 6	
	£675 1 2	
Less Balance of Scholarships for 1915 lapsed	100 0 0	
		£575 1 2
„ Balance, being excess of Income over Expenditure		322 18 5
		£897 19 7

INVESTED FUNDS OF THE INSTITUTE.

	£	s.	d.
£3744 North-Eastern Railway 4 per cent. Preference Stock, cost ...	£4,297	6	7
£788 North-Eastern Railway 4 per cent. Guaranteed Stock, cost ...	1,008	14	0
£79 4s. 5d. "B" Annuity, Scinde, Punjaub, and Delhi Railway, expiring 1958, with a Sinking Fund to replace the amount of Stock, cost ...	1,999	0	7
£50 1s. 8d. "B" Annuity, Great Indian Peninsula Railway, expiring 1948, with a Sinking Fund to replace the amount of Stock, cost ...	1,267	6	0
£1500 Buenos Ayres Great Southern Railway 4 per cent. Debenture Stock ...	1,594	12	9
£1000 Commissioners for the Port of Calcutta 4 per cent. Bonds, 1939, cost ...	982	10	0
£800 Trustees of the Port of Bombay 4 per cent. Bonds, 1939 ...	809	0	0
£750 Great Central Railway 3½ per cent. Second Debenture Stock, cost ...	659	12	6
£750 Great Northern Railway (Leeds, Bradford, and Halifax) 6 per cent. Guaranteed Stock, cost ...	1,140	8	6
£511 South-Eastern Railway 3½ per cent. Perpetual Debenture Stock, cost ...	449	4	5
£712 1s. 3d. War Stock 4½ per cent. 1925–45 (since converted), cost ...	698	18	8
	£14,906	14	0

INVESTMENTS ON ACCOUNT OF LIFE COMPOSITIONS.

	£	s.	d.
£1330 North-Eastern Railway Irredeemable 3 per cent. Debenture Stock, cost ...	£1,254	17	6
£335 London Electric Railway 4 per cent. Perpetual Debenture Stock, cost ...	304	14	11
£335 Metropolitan District Railway 4 per cent. Prior Lien Debenture Stock, cost ...	333	11	2
£335 North British Railway 4½ per cent. 1875 Irredeemable Preference Stock, cost ...	371	13	9
	£2,264	17	4

ANDREW CARNEGIE RESEARCH SCHOLARSHIP FUND.

	£	s.	d.
£2250 Newcastle-upon-Tyne Electric Supply 4½ per cent. Consolidated First Mortgage Debenture Stock, cost	£2,261	10	0
£2600 Great Central Railway 4½ per cent. Debenture Stock, cost ...	2,384	5	0
£3000 Great Central Railway 3½ per cent. Debenture Stock, cost ...	2,055	13	6
£5000 Great Northern Railway 3 per cent. Debenture Stock, cost ...	3,186	16	9
£5000 Great Eastern Railway 4 per cent. Debenture Stock, cost ...	4,080	16	0
£2000 Caledonian Railway 4 per cent. Debenture Stock, cost ...	1,693	0	6
£2000 North British Railway 3 per cent. Debenture Stock, cost ...	1,249	12	6
£2000 Taff Vale Railway 3 per cent. Debenture Stock, cost ...	1,204	5	3
£2560 4s. India 3 per cent. Stock, cost ...	1,525	3	3
£2300 India 3½ per cent. Stock, cost ...	1,600	2	9
	£21,241	5	6

(Signed) ILLTYD WILLIAMS, *Hon. Treasurer.*
G. C. LLOYD, *Secretary.*

I have examined the above Balance Sheet and accompanying Income and Expenditure Accounts with the Books and Vouchers of the Institute, and certify them to be correct. I have also verified the Balance at the Bankers and the Securities for the invested Funds as shown above.

(Signed) W. B. KEEN.
Chartered Accountant.

23 QUEEN VICTORIA STREET, LONDON, E.C. 4, 16*th April* 1917.

BESSEMER MEDAL FUND (Trustees: Sir HUGH BELL, Bt., Lord AIREDALE, and FRANCIS SAMUELSON, Esq.).

£534 London and North Western Railway 3 per cent. Debenture Stock.

The PRESIDENT formally moved the adoption of the Report of the Council and the Statement of Accounts.

Mr. GEORGE HATTON (Dudley) said he desired to raise a point arising out of the Report of the Council dealing with the appointment of Technical Committees. He thought in the appointment of Committee No. 4, dealing with iron and steel foundry practice, justice had scarcely been done to a branch of the iron foundry business in which he considered the iron and steel trade were more interested than in any other, namely, heavy iron foundry practice, rolling-mills, rolls, and all the accessories that were required by the trade. That branch of the trade was practically unrepresented on the Committee, and with the permission of the meeting he desired to suggest that the names of Mr. J. Arthur Hampton of Taylor & Farley, West Bromwich, and Mr. Isaac E. Lester of C. Akrill & Company, West Bromwich, be added to the Committee. South Staffordshire was essentially the home of that trade, and it was practically unrepresented on the Committee.

Mr. J. E. FLETCHER (President of the Staffordshire Iron and Steel Institute) said he desired to support the suggestion that had been made by Mr. Hatton. Both Mr. Hampton and Mr. Lester were particularly interested in heavy castings in the Staffordshire district, and if the Council would favourably consider the suggestion that had been made it would afford much pleasure to South Staffordshire.

The PRESIDENT said the way in which he would ask Mr. Hatton to allow him to deal with his suggestion was to submit to the Council the names he had proposed for addition to Committee No. 4, and to bring the proposal up for consideration at the next Meeting of the Council. It was hardly possible at a General Meeting to accept nominations to a Committee, as under Bye-law 25, all Committees had to be appointed by the Council. He might also add that the Council had given to all the Committees the power to co-opt members specially qualified to assist them in their work. In the meantime he heartily welcomed the suggestion that had been made.

Professor T. TURNER (Birmingham University) inquired whether the very important report referred to on p. 15 of the Council's Report, dealing with the iron ore resources of the United Kingdom, British Dominions, and foreign countries was private, or whether it would subsequently be available for the use of the members?

Sir ROBERT HADFIELD said he understood that the Advisory Research Council would make arrangements to place a certain number of copies of the Report at the disposal of members, as well as to present copies to universities and scientific societies.

Mr. WALTER DIXON, in seconding the motion for the adoption of the Report and the Statement of Accounts, said he desired to repeat, in a formal way, the usual statement made at the Annual Meetings of the Institute—that the members were much gratified at the work the Council had done during the past year; but on the present occasion he thought the motion called for exceptional treatment. The members noticed with pleasure that the Council had taken definite and clear steps and shown an activity during the past year in certain directions in which the ordinary members had felt for some time that they would do well to act. In that sense there was cause for real gratification and satisfaction. The members had heard with pleasure that the Institute had on its own account, and apart from Government or other control, appointed five Technical Committees dealing with different branches of the industry. The advice he wished to tender to the Council, on behalf of the ordinary members, and based on a good deal of experience, was that they should "do things"; "not dream and talk them." So long as the Committees were self-contained and embraced within the Institute itself, he thought and hoped there was a possibility of getting things done. Evidence was available that in regard to one or two subjects in which many of the members were concerned, it was possible, during the present times and existing conditions, to do things that in ordinary times were not possible. He thought there was a special cause for complimenting the Institute on the formation of a "Class of Associates." Those who had experience with the Provincial Institutes—and he (Mr. Dixon) had been for

a long time closely associated with the West of Scotland Iron and Steel Institute—had often felt that definite and clear advantages would be derived by the central Institute by the formation of such a class of member, and by the official recognition by the Institute of the Provincial Institutes. The future membership of the Institute was being well catered for by the creation of the Associate Class, and it was now up to the various districts, as well as individual firms, to emulate the example set by Sheffield and district, which had at this meeting proposed over fifty gentlemen for membership as Associates. Other central Institutes as large and as powerful had, by associating themselves with Provincial Institutes, added greatly to their value and interest. The papers read at the various Institutes were communicated to the Provincial Institutes, and, as occasion or desire arose, were discussed in the Provincial Institutes, adding largely, as may be readily understood, to the value of the printed Transactions. He mentioned this for the consideration of the Institute. It had been suggested to him that he might throw out one other point for the consideration of the Council. The members were at present living in strenuous times; they did not know what would happen between this and the September Meeting, but he suggested that if it were at all practicable some means should be afforded during the September Meeting whereby another popular phase of the Institute's work should have a chance of operating again, viz. that opportunities should be given outside the morning meetings for the members to meet together and talk over various matters of mutual interest, not in a formal but in a social manner.

The resolution for the adoption of the Report and the Statement of Accounts was then put and carried unanimously.

Amendment of Bye-laws.

The President said that the next business was the adoption of the new Bye-law as proposed at the Autumn Meeting on September 21, 1916. He begged leave to move:

> "That the new Bye-law as approved at the last Autumn Meeting be adopted for incorporation in the existing Bye-laws of the Institute, subject to the approval of His Majesty's Lords in Council in accordance with Clause 7 of the Charter."

The SECRETARY read the new Bye-law, as follows:

> "The Council shall have power to decree the suspension of any ordinary or honorary member, or to remove from the list of members of the Institute the name of any ordinary or honorary member for wilful contravention of the Bye-laws or for any other reason which shall seem to them sufficient. Provided, however, that no member, whether ordinary or honorary, shall be suspended, nor his name be removed from the list of members, unless the Council so decide by a majority of at least two-thirds at a meeting at which there are not less than twelve members of Council present and voting."

Mr. E. ADAMSON (Sheffield) formally seconded the motion, which was put to the meeting by the President and carried unanimously.

PRESENTATION OF BESSEMER MEDAL.

The PRESIDENT said it was now his pleasant duty to present the Bessemer Gold Medal to Mr. Andrew Lamberton, Vice-President, who was well known to all the members as the head of his firm at Coatbridge, and for his work in connection with the iron and steel industry, mainly in the direction of the development of the principal mechanical engineering appliances in use in the manufacture of iron and steel. In particular, he was the author of many important improvements in rolling-mill machinery, by which the capacity of mills had been increased and the cost of production lowered. From time to time he had communicated to the Institute valuable papers dealing with the driving of rolling-mills and their design. It should be explained that this year the form of the presentation differed in one important respect from the form in which it had always been made in previous years. Mr. Lamberton had, for patriotic reasons, foregone the acceptance of a medal struck in gold, and the Institute was consequently presenting to him at present nothing more than the diploma to which the usual metal replica of the medal was attached. The Institute was asking Mr. Lamberton to accept this in token of their recognition of his eminent services in the development of mechanical engineering as applied to the manufacture of iron and steel, and would look forward to the time at no distant date when

they would hope to supplement the parchment with the real object.

Mr. ANDREW LAMBERTON, Vice-President, in reply, said he desired to thank the Council most sincerely for the great honour of which they had made him the recipient that morning. The Bessemer Medal was, he thought, considered by the entire membership as the blue ribbon of the iron and steel industry. It was also the highest honour in the power of the Institute to award; and when it was borne in mind that of all scientific bodies the Iron and Steel Institute was perhaps the most cosmopolitan, drawing its membership from practically every civilised nation in the world, the honour was all the more richly enhanced. So fully did he realise all this that he felt it would be pure presumption on his part were he for a single moment to think that the award had been made to him in a purely personal sense. He was sure he rightly interpreted the action of the Council as being a desire on their part to make the presentation of the Medal a recognition of the valuable, and indeed wholly indispensable, services which the profession of engineering, to which he had the honour to belong, had rendered towards the rise, progress, and present prosperity of the iron and steel industry of this country. He yielded to no one in admiration of the magnificent services which had been rendered on the purely scientific and research side of steel-making by our chemists and metallurgists who by long, arduous, and most painstaking labours had in very truth laid the foundation upon which this whole-world industry of iron and steel had been reared. Yet it was equally true to say that but for the work of the engineer, this beautiful material, steel, which had been given to them by the scientists, could hardly have been more than a successful laboratory achievement. It had been by the work of the engineer that steel had been brought into the position of being the world-wide commodity which was entering every day more and more both into their national and individual life. This was so much of a commonplace that people sometimes forgot how much they owed to steel-makers and the engineers who fashioned it into so many useful structures. They rode on steel railroads, drawn by steel locomotives; they crossed rivers on steel bridges; they sailed in steel steamships; they rode in steel motor-cars; and in this

awful conflict on the Continent of Europe, they were fighting the battle of freedom and the cause of humanity with steel guns and steel shells.

So deeply did he realise the honour that had been done him that he wished to regard it, as far as it possibly could be, a collective honour to all his brethren of the engineering profession, and particularly that section which had devoted so much time and thought to the development and perfecting of steelworks machinery. He hoped that had been the intention of the Council, and he trusted that every member of the profession would accept his full share, as he gratefully accepted his own little share of it.

There was one personal note he desired to add, namely, that he felt very proud to be the first Scotsman who would take this Bessemer Medal home with him to their little country north of the Tweed. That pleasure was greatly accentuated by the fact that it had been handed to him by a very distinguished Scotsman in the person of the President. There were some rather weird opinions held in these more southern latitudes in regard to Scotsmen. He had heard it said that a Scotsman was believed in the South to be a person who kept the Sabbath and everything else he could lay his hands on! Well, probably all decent Scotsmen would be glad to plead guilty, if they conscientiously felt they could do so, to the first part of that indictment; and with regard to the second part, he was prepared to plead guilty at least to this extent, that now that he had got his hands on this Medal, he meant to keep it, to treasure it, and to value it as his most precious possession, for not only would it always remind him of the great honour which he had received from the Iron and Steel Institute that morning, but it would never fail to remind him also of many precious friendships which it had been his privilege to make amongst the membership and the Council of the Institute—memories of friendships which he would carry with him and cherish to the last days of his life.

The paper by Mr. Cosmo Johns (Sheffield) was then read and discussed, and the meeting was adjourned to the next day.

The Chair was taken by the President at 10 A.M. on the morning of Friday, May 4.

Carnegie Research Fund: Grants in Aid of Research Work.

The Secretary announced that awards had been made by the Council from the Carnegie Research Scholarship Fund to: W. C. Hancock (London), £50, to enable him to continue his investigations on refractory materials, with special reference to the manufacture of coke-oven bricks (Mr. Hancock received £100 in 1916 to assist him in carrying out the research); J. L. Haughton and D. Hanson (National Physical Laboratory), £100 to enable them to continue their joint research on iron-phosphorus and iron-carbon-phosphorus steels (the applicants received £100 in 1916 in aid of the research); J. E. Hurst (London), £100 for an investigation on the wearing and the microstructure of worn cast-iron specimens; and J. H. Whiteley and A. F. Hallimond (Middlesbrough), £100 for a joint research on the chemical detection of strain in iron and steel.

Particulars concerning the previous work and position of Messrs. Hancock, Haughton, Hanson, and Whiteley were given in the *Journal of the Iron and Steel Institute*, 1916, No. I. p. 28.

The following are brief notes of the careers of Messrs. Hurst and Hallimond:

Mr. J. E. Hurst has, since 1912, been Research Metallurgical Chemist to Messrs. Hornsby & Sons, of Grantham and Stockport. He was previously Chief Assistant Chemist to Messrs. Beyer, Peacock and Co., Gorton. In December 1916 he presented a paper on "Cast Iron, with Special Reference to Engine Cylinders," to the Manchester Association of Engineers, and the proposed research for which the present grant is made is to be a continuation of the pioneer work in the above-mentioned paper.

Mr. Arthur Francis Hallimond from 1909–1912 studied at Pembroke College, Cambridge. He has since held the position of Assistant Curator at the Museum of Practical Geology, and is at present on special leave for service with the South Durham Steel and Iron Co. He is the author of various papers, and the present grant is awarded to him jointly with Mr. J. H. Whiteley.

Papers by Messrs. J. N. Kilby (Sheffield), Lawford H. Fry (Burnham, Pa., U.S.A.), and L. Grenet (Firminy) were then read and discussed, the remaining papers, by F. C. Langenberg (Harvard,

U.S.A.), G. P. Raidabaugh (Sparrow's Point, U.S.A.), N. Tschischewsky and N. Schulgin (Tomsk, Russia), and F. C. Thompson (Sheffield), being taken as read.

The PRESIDENT proposed a vote of thanks to the President and Council of the Institution of Civil Engineers for their kindness in affording the Institute the use of their building for the meetings.

The motion having been carried unanimously,

Mr. A. LAMBERTON (Vice-President) said that before the meeting closed he would ask the members to accord a hearty vote of thanks to the President for his conduct in the Chair. He was sure all the members felt that the President had been of great assistance in carrying on the business of the Institute, and considering the extraordinary pressure upon his time in these war days, there was a very great debt owing to him for presiding during the whole of the meeting.

The motion having been unanimously agreed to, the PRESIDENT briefly returned thanks and the proceedings then terminated.

PROPERTIES OF THE REFRACTORY MATERIALS USED IN THE IRON AND STEEL INDUSTRY.

By COSMO JOHNS, F.G.S. (Sheffield).

INTRODUCTION.

Writers so rarely state exactly what they mean by refractory materials that a definition may not be out of place even though its terms may not find general acceptance. As the metallurgical processes employed in the iron and steel industry involve heat exchanges, and high temperatures are necessary for most of the reactions that occur, special materials are required for the construction of the portions of the furnaces, ovens, and vessels employed that are exposed to high temperatures and are in contact with the solid, liquid, and gaseous substances taking part in the reactions. These special materials are refractory if they are capable of fulfilling the structural duties required, while subjected to the high temperature necessary for the process employed, and are themselves unaltered during its progress. The conditions that prevail when metallurgical processes are being carried out vary so much, and the problems presented by the occurrence of slags sometimes basic and sometimes acid, of atmospheres now reducing and again oxidising, call for so many mutually exclusive properties in the refractory material employed, that only an infusible and non-volatile substance, with no volume change during variations of temperature, inert from a chemical standpoint, and with sufficient structural strength yet a non-conductor [1] of heat, would be considered ideal. No such substance is known and very probably does not exist. Hence any refractory materials employed in the metallurgical art will be the nearest approach available to the ideal for the particular process employed. And as metallurgical processes are in practice conducted on commercial lines, the refractory material employed will be that which enables a given unit of final product to be produced at the lowest cost. Fused silica and platinum are useful refractory materials in laboratory experi-

[1] Except in those cases where thermal conductivity in a high degree is desirable.

ments, but are excluded from consideration in commercial processes for obvious reasons. In practice, therefore, the refractory material selected is never ideal and always a compromise. The purpose of this communication is to discuss the properties required in any refractory materials employed, to point out their importance [1] with a view to stimulating research, and to invite those familiar with the needs of the iron and steel industry to amplify or correct the suggestions made. It is hoped that any research undertaken can then be applied in the direction most urgently needed and where the most immediate beneficial results can be obtained. At the same time any advances in our scientific knowledge of the properties of available refractory substances, even if not immediately applicable, will be welcome as the foundation of later progress in practice.

Available Materials.

With the exception of carbon, and its compounds with silicon, which have a limited application, the available refractory substances are chiefly the oxides SiO_2, Al_2O_3, CaO, MgO, Cr_2O_5, or mixtures of these with oxides of iron, K_2O, Na_2O, and traces of other substances, regarded as impurities, some of which may function as catalysts. The materials available are therefore strictly limited; they never occur in a state of purity in nature. Their manufacture into refractory products involves in many cases sizing, agglomeration or bonding, and final heating to a temperature that varies according to the purpose for which the product is intended and the functions it has to perform. The problems that arise are not solved by a knowledge of the properties of the compounds mentioned; they are complicated by the presence of impurities and the varying nature of the bonding material employed. The final product, as delivered to the user, is always a mineral aggregate, often of great complexity. They possess no fusion point, but rather a range during which softening, at first incipient, at last, with increasing temperature, causes the material to fail to perform its functions. The constituents have varying melting points, and during heating they invert and new phases appear. Some inver-

[1] The Presidential Address of Sir Robert Hadfield (Faraday Society: General Discussion on Refractory Material; *Transactions of the Faraday Society*, 1917, vol. xii.) should be consulted as an important plea for research.

sions, involving serious volume changes, should be completed during manufacture, but often are not. This is not imputing blame to the manufacturer, for the temperatures required for such changes are rarely known, and even when known as a result of experiments under laboratory conditions, it does not follow that they apply to manufacturing processes. The art has been so long in front of the science of the refractory industry that the most urgent need at present is for an expression, in terms of scientific precision, of the most successful practice in manufacturing the refractory product and of the physico-chemical changes which take place when they are used.

Tenacity and Compressive Strength.

Tenacity and compressive strength at ordinary temperatures are valuable only in so far as they permit the refractory products to be transported and enable them to withstand the structural stresses to which they are exposed when used. This is not difficult to attain. It is when the material is exposed to high temperatures that the value of these properties becomes most important. The abrasion caused by the movement of solid substances while in contact with their heated surfaces is important, while the erosion caused by the passage of dust-laden gases at high velocities becomes serious in time. Little or nothing is known of the conditions that favour or retard abrasion and erosion. High tenacity, which in most cases would mean that of the bonding or of the most fusible constituent, is most probably the desired property. It is the surface exposed to the highest temperature which suffers, for it is the one that is in contact with the moving solids, liquids, or gases. Compressive strength is rarely a cause of failure, for the bulk of the refractory material is at a lower temperature than the face and therefore less affected. There is, however, urgent need for accurate determination of the two properties under discussion at wide ranges of temperature for the more important materials under both oxidising and reducing conditions.

Corrosion Changes.

Not less important than resistance to high temperature with concurrent abrasion and erosion is resistance to the corrosion

caused by slags and gases. The effect of acid slags on basic refractories and of basic slags on acid refractories are familiar, while a most striking example might be indicated in the marked corrosion of the silica bricks in the gas ports and uptakes in open-hearth furnaces, due to the alternating passage of oxidising and reducing gases with the resulting formation of fusible silicates. A factor conducive to rapid corrosion in the last case is the absence of large particles of silica in the bricks employed and the presence of excessive pore spaces. Here again little has been published and few observations recorded. The effect of the alkalies found in certain coals on the refractories used in coke-oven construction is serious, and here too little is known as to the real nature of the destructive influences at work.

Volume Changes.

Every element or compound used as a refractory undergoes changes in volume during heating and cooling. Apart from the fact that these volume changes may, and do at times, cause disintegration with the consequent lessening of the useful life of the material, abnormal expansion causes structural difficulties, while contraction may be even more undesirable, permitting the passage of gases from one part of the furnace to another. In the case of coke-ovens the retention of gas-tight partitions is absolutely necessary, and this involves the use of a refractory material which does not undergo appreciable volume changes. This apparent contradiction of the first statement simply means that a mixture [1] of substances with volume changes of opposite sign are employed, viz. clay and silica. But while the contraction of the burnt clay is fairly regular with increased temperatures, quartz, which is the form of silica found associated with it in nature, has an inversion point at which it becomes tridymite. In the presence of certain compounds this inversion takes place at a temperature lower than that at which coking is carried on. In their absence the inversion is retarded and does not take place until a temperature higher than that usual in coking practice is attained. The conditions that determine these differences in the inversion temperature of quartz do not appear to be known.

[1] Professor Fearnsides has recently discussed this problem, see *The Quarry* for March and April, 1917.

Heat Conductivity.

If the refractory materials used possess a fusion point or softening range higher than the maximum temperature to which they are exposed, it would in most instances be desirable that they should be non-conductors of heat, for radiation losses would then be at a minimum. More often the prevailing temperatures approach and sometimes exceed that at which fusion or softening occurs. In those cases it is necessary to encourage radiation from the surface farthest removed from the heated surface, in order to cause a steep temperature gradient from the heated to the cooler face. In special cases cooling devices are necessary to prevent the rapid destruction of the material employed. Good conductivity for heat is most desirable where the material is used to form walls which transmit heat from the burning fuel to the contained charge which is being heated The melting of steel in crucibles and the coking of coal are instances where a refractory material with good heat conductivity is required.

Texture and Porosity.

These physical characteristics of refractory materials determine in large measure their suitability or otherwise for particular duties. Owing to the complex nature of most of the materials used in practice their properties are not those of the simple minerals of which they are composed, but the resultant of variations which are sometimes of opposite sign and are always varying at different rates. The relative size of the grains [1] employed, the extent of the surface exposed by the more resistant constituents to the others used as bond or matrix, are most important factors in contributing to the ability of the material to perform useful service. Another point of some importance is the influence of mass in promoting or retarding inversions. Some of these inversions take place almost instantly once the critical temperature has been reached, but with others marked hysteresis occurs. Porosity must always occur when the refractory material is composed of more than one constituent, and where their chief volume changes are dissimilar or

[1] For the influence of grain size in the case of the silica brick see Cosmo Johns' "Silica as a Refractory Material," Faraday Society: General Discussion on Refractory Materials. *Transactions of the Faraday Society*, 1917, vol. xii.

occur at different temperatures.[1] Little is known of the effect of porosity on the properties of refractory materials. That the pores encourage the deposition of extraneous substances in the interior of the bricks, and that they render the structure permeable to gases, is of course obvious.

Stresses caused by Temperature Changes.

The stresses caused by temperature changes are due to the volume changes which take place during heating. If the refractory material happens to be a good conductor of heat these are not serious, unless one face is rapidly heated and the distortion produced exceeds the tenacity of the material. The remedy available is to avoid rapid temperature changes, and whenever possible to raise the temperature of the material during the burning stage of manufacture well above that at which the inversion to which the principal volume change should take place, and to hold it at that temperature long enough for the inversion to be completed. The "spalling" of magnesite bricks which sometimes occurs has been thus explained,[2] and it is certain that the excessive expansion of silica bricks would be avoided if the manufacturer could ensure the completion of the quartz-tridymite inversion during burning. Despite the considerable advances in our knowledge of the inversions of silica[3] made recently, their bearing on the problems that face the manufacturer are not yet sufficiently clear.

Need for Further Research.

Advances in the art of metallurgy are largely conditioned by the nature of the refractory materials available. The manufacture of these materials is based almost entirely on empirical rules and the experience of the men employed. Such rules are the result of experiences gained during a century or more by a rude process of trial and error, but where there were but very inadequate means of correlation. The methods employed to-day represent the survival of the fittest by the searching test of commercial

[1] A most useful discussion of the "Deterioration of Refractory Materials," by H. B. Cronshaw, appeared in *Carnegie Scholarship Memoirs*, 1916, vol. vii.
[2] Mellor, *Engineering*, 1917, p. 317, April 6.
[3] Fenner, *American Journal of Science*, 1913, vol. xxxviii. p. 331 *et seq.*

success, but it by no means follows that they represent the best attainable. Further progress, if made at all, can only be slow and uncertain, and by consent it is now admitted that only by adequate and well-directed scientific research can such progress be accelerated. The first step—and in all probability the one easiest to take—would be to prepare specifications for the most important refractory products expressed in terms capable of precise measurement or description, basing the specification on the best current practice. This would only be following the excellent example of the gas industry.[1] But specifications at their best only serve to stereotype the current practice of their day. These specifications should be the starting point of systematic research which should cover, not only the problems that occur during manufacture, but the occurrence in nature and characteristics of the raw materials.[2] Their concentration and purification, proximate and ultimate analysis, mineralogical description and thermal analysis[3] are all points on which additions to our present knowledge would be of great value. But the refractory materials are so complex,[4] and the problems involved are so difficult of direct attack, that any contributions to our knowledge of the properties of the pure minerals, or of the impure aggregates which are used in practice, would be welcomed even if their immediate application did not happen to be possible.

A schedule of the requirements of the iron and steel industry, so far as the most pressing problems affecting the use of refractory materials, is appended to this communication. It is to be regarded as tentative only, and its most useful function will be to provide a basis for discussion, in the course of which it is hoped that corrections and additions will be made, and thus enable a reasoned statement of the requirements of the great industry represented by this Institute to be made.

[1] "Standard Specifications for Refractory Materials," published by a joint committee of the Institution of Gas Engineers and the Society of British Gas Industries in 1912.

[2] The Geological Survey, under the direction of Dr. A. Strahan, F.R.S., have in preparation for early publication a memoir on the mineral resources of this country, dealing specially with refractory materials.

[3] Thermal analysis by the Frankenheim (heating and cooling curves) method appears to be of limited application in the study of silicates. Much success has been obtained by the Hancock and Neville method of quenching from high temperatures, after equilibrium has been attained, with subsequent microscopic examination.

[4] The pioneer work (see "Collected Researches," vol. i.) in this country is that under the direction of Dr. Mellor at the Pottery Laboratory, Stoke-on-Trent. The scientific study of refractory materials is now, however, being initiated or contemplated in several British universities and institutions.

Schedule of the Principal Refractories used in the Iron and Steel Industry, with Notes on their Behaviour under Service Conditions.

Service.	Description of Product.	Raw Material.			Notes on Behaviour under Service Conditions.	Remarks.
		Description.	Former Source of Supply.	Present Source of Supply.		
Coke-ovens	Coke-oven bricks for linings [1]	Fireclay	Home and abroad	Home	The imported coke-oven brick was generally superior to the home-made product. The difference is now being reduced and good local bricks are being made, but the corrosion caused by salt vapours when using certain coals has not been overcome in either the imported or local bricks.	The difficulty experienced before and since the outbreak of war was largely due to lack of knowledge of the conditions to be met, and of the properties of the foreign clays or admixture of clays and their nearest British equivalents.
Blast-furnaces	Blast-furnace bricks	Fireclay	Home	Home	Abrasion and disintegration	Any advance in our knowledge of the properties of fire-clay bricks at high temperatures would help in improving the quality of those used in blast-furnaces.
	Carbon bricks	Carbon in the form of coke or anthracite	...	...	Not available	There appears to be much still to be learnt regarding the texture, bonding, and baking of carbon products such as bricks, &c.
Electric furnaces	Magnesite bricks [1]	Magnesite	Abroad	Abroad	High cost. Low softening point. Spalling if rapidly heated.	Though better bricks are being made, much remains to be done before the difficulties are overcome.
	Special roof bricks	Silica	Home	Home	The roof is the weak point at present. No satisfactory brick has yet appeared. The best silica bricks have too short a life. The reducing atmosphere and its vapour constituents impose severe conditions at the temperature employed.	It is here that new types of refractories appear to be required.

Open-hearth furnaces	Silica bricks [1]	Quartzite	Home	Home	Variability in quality. Erosion by rapidly moving dust-laden gases. Disintegration, spalling when rapidly heated.	Differences in quality as between different makers and sometimes in the product of the same maker is evident.
	Magnesite bricks	Magnesite	Abroad	Abroad	See Electric Furnaces	See Electric Furnaces
Casting operations in steelworks	Stoppers, nozzles, runner bricks for multiple casting	Fireclay, but magnesite & mixtures of fireclay and carbon have been tried for nozzles	Home and abroad	Home and abroad	Stoppers and nozzles are rapidly eroded by the rapidly moving stream of liquid steel under conditions not well understood. Magnesite has given good results when fireclay has failed.	The problem here is not so much to find stoppers and nozzles to suit every condition but to determine first those conditions, and then select the most appropriate material for that particular
Special [1]	Chromite bricks	Chromite	Abroad	Abroad	Imperfectly known, but arousing much interest	A considerable, if restricted field, is open for the application of any new knowledge of the properties of these lesser known refractories.
	Bauxite ,,	Bauxite	Home and abroad	Home and abroad		
	Zirconia and other rare earths. Spinel. Fused magnesia, lime, and other fused oxides	...	Abroad	Abroad		

[1] Urgently require investigation.

APPENDIX (*added June* 9, 1917).

As a result of the discussion and of many private communications received before and since the reading of the original paper the schedule has been revised in some particulars. It is clear that there is a widespread desire that improvements in the quality of the principal refractory products should be effected, and it is certain that the leading manufacturers of refractories are eager to do what is possible. On both sides there is abundant evidence of willingness to co-operate, and thus bridge the gap that formerly divided makers and users. There is further a feeling that recent advances in pure science have not received that attention and application to industrial problems that their importance deserves. There is a growing interest in the possibilities of the rarer refractory materials, and the great increase in the number of electric furnaces used for steel manufacture has no doubt contributed largely to this movement. In addition to these special requirements the trend of metallurgical practice in iron and steel manufacture, and in the coking of coal, has been towards increasing the velocity of the reactions involved by the use of higher temperatures while striving at the same time to reduce heat losses with a view to securing economy in fuel consumption. Now progress in this direction is largely, and in some cases entirely, conditioned by the properties of the refractory materials available.

There is much evidence that many refractory products largely used in the iron and steel industry have a less useful life than characterised them before the war. The simplest explanation is to assume that their quality has deteriorated, but an equally justifiable assumption is that the war has introduced service conditions much more severe than those hitherto experienced. The correct explanation would probably include both these factors, and should not exclude a recognition of the merits of the many manufacturers of refractories who have under great difficulties striven, and not without success, to meet the abnormal demands caused by the expansion of the various metallurgical industries during the progress of the war. There were many difficulties experienced in this country in the manufacture of special coke-oven bricks before the war, and although some of

these difficulties have been, or are being, overcome others remain, and in certain districts are intensified owing to the liberation of sodium chloride vapour and perhaps other harmful constituents during the coking process. This indicates a vast field for research, only partly covered by the work now in progress, where new contributions to our knowledge would have far reaching applications. From all of the steel-producing districts there is a demand for silica bricks[1] that would give a longer life under present conditions. While certain brands maintain a commendable regularity of quality others vary considerably, and it is evident that in these last-mentioned cases the difficulty is caused by lack of scientific control rather than by differences in the quality of the raw materials used. Recent advances in our knowledge of the silica minerals suggest that this demand might be met by co-operation between research works and the makers and users of silica bricks. That finality has been reached in the evolution of the silica brick cannot be admitted. The fact that unburnt lime-silica bricks, where the bond was steam-hardened in an autoclane, have been successfully used in open-hearth furnaces—under a very carefully controlled rate of heating until the maximum temperature was reached it should be noted—is very suggestive, while the very successful use of a mixture of red jasper and quartzite[2] for making silica bricks which were tried at the Imperial Steelworks of Japan serves to indicate that much remains to be done. It is admitted that the magnesite bricks made in this country, and it would appear that this applies to the United States as well, from the very pure Grecian magnesite have not been so successful as the Styrian product. But it also remains true that in no case has it been possible to utilise the high melting point of magnesia, and both the Styrian and home products fall far short of the theoretically possible. Perhaps the true solution lies in the use of fused pure magnesia, as suggested by Kilburn Scott several years ago. This would lead to the necessity for a more careful study of the possibility of using the pure oxides—fused silica is an example—such as magnesia, lime, zirconia, and mixed oxides such as spinel.

[1] For an important discussion of the constitution and manufacture of the silica brick see "Dinas," by F. Bondolfi, Milan, 1917. I have to thank Mr. G. C. Lloyd, Secretary of the Iron and Steel Institute, for calling my attention to this.

[2] Cosmo Johns, "General Discussion on Refractories," Faraday Society, 1917, p. 82. My thanks are due to Captain Noda, Imperial Japanese Navy, for having, since that discussion, forwarded me specimens of the brick and the jasper and quartzite from which it was made.

So far only four types of refractories have been suggested as deserving earnest attention, but as a matter of fact they cover almost the entire field, for research could hardly be confined so strictly that only definite and narrow problems were considered, so that nothing less than a wide and far reaching research, covering practically the whole field of refractories, would meet the growing demand of the iron and steel industry. The remarks that follow are an indication of the character of the information that is required rather than a list of definite problems that demand solution.

A. Raw Materials.

1. A comparative investigation of the special clays and other special raw material used abroad, or formerly imported into this country, and their nearest British equivalent.

2. Complete analyses, proximate and ultimate, and petrological description of the principal raw materials available in this country.

3. Influence of impurities on the inversion temperatures of the principal compounds used in the manufacture of refractory products.

4. An inquiry into the practicability of eliminating lime from dolomite with a view to manufacturing magnesite bricks.

5. The concentration, purification, and preparation of the raw material for the manufacture of chromite, bauxite, spinel, zirconia, and other rarer refractory materials.

B. Refractory Products.

1. An investigation of the physico-chemical changes that occur during the manufacture and subsequent utilisation, under service conditions, of the more important refractory products.

2. The influence of texture, bond, and previous thermal history of the principal refractory products on their durability under service conditions.

3. The erosion of refractory materials by rapidly moving currents of liquid steel and dust-laden gases.

4. Physical and chemical properties of the more important refractory products at various temperatures, especially at the highest to which they are subjected during industrial service.

5. Corrosion of coke-oven linings by salt vapours and steam.

6. Plumbago and other crucibles.

DISCUSSION.

Mr. Cosmo Johns said he thought it was desirable to explain to the meeting the reasons that had led up to the presentation of the paper to the Institute. It might be known to some of the members, but possibly not to all, that on November 8, 1916, a symposium of papers was read and a discussion on refractory materials took place at a largely attended meeting of the Faraday Society, at which Sir Robert Hadfield presided. A large amount of interest was created in the subject, and as a result a number of most valuable papers and *résumés* were brought together. It led everybody who attended the meeting to consider that something further should be done in order to get the various efforts that had been made to improve refractory materials and prosecute research in that direction co-ordinated. As the result of that general feeling, the Iron and Steel Institute, the Faraday Society, and one or two other societies, issued an invitation to all the leading technical societies and institutions to send two representatives to a joint conference to consider the question with the object of seeing what could be done. That conference met on March 22, 1917, again under the chairmanship of Sir Robert Hadfield. The matter was considered very fully, and a small Research Committee was appointed to report on a number of important subjects to a later meeting of the conference, with a view to enabling it to carry out its duty of formulating some general national scheme. That small committee met under the chairmanship of Sir Robert Hadfield. He (Mr. Cosmo Johns) was a member of it, and it became his duty to prepare a schedule of the requirements of the iron and steel industries for submission to the conference. As the meetings of the Institute fortunately were being held previous to the next meeting of the conference of all the societies, he thought he had better relieve himself of the responsibility of having prepared the schedule by submitting it to the members for their criticism and addition. He therefore craved the indulgence of the members in submitting the paper to them. He asked them to criticise the schedule but not the last column, which he intended to revise. He trusted he would be able to put in such words as would justify research on any department of practice in regard to refractory materials. Information was urgently required for the purposes of the committee on the question of what materials were formerly available and were now unobtainable probably as a result of war conditions; what were the materials, if any, which had shown deterioration in quality; what were the special problems which had arisen in the industry as a result of war conditions; and finally, what, if any, were the problems that seemed to demand instant action.

Sir Robert Hadfield, Bart., F.R.S., Past-President, in opening the discussion, thought the members were very much indebted to the author for a paper of unusual value. The subject was one to which in

the past they had not paid the attention it deserved. Whether the refractory material makers were to blame or not it was difficult to say. The stress of war had produced a demand for a great increase in the number of furnaces and in the capacity for steel production, and possibly that was one of the reasons why manufacturers were finding out some of the weaknesses of the refractories they used formerly and about which they were perhaps not so critical as at the present time. He did not wish to say anything derogatory to the refractory makers, because many of them were paying the utmost attention to that important branch of metallurgy. Not long ago, however, he had met makers of refractory materials who did not even have an analysis made of their product. That showed there was yet room for improvement in that direction. Those who made steel required analyses by the thousand or the ten thousand, and he was quite sure that in the same way it was necessary to have constant analyses made of refractory materials. There were other conditions besides the actual composition that had to be kept in view, namely, the structure of the material. The same remarks applied to the making of firebricks. His firm had asked some firebrick makers to burn bricks for them at a certain temperature, and he was sorry to say they had discovered that the makers had no means of determining the temperature. It was impossible to produce a brick of the best possible quality unless it was treated in the same manner as steel was annealed. Steel was annealed at certain temperatures, and refractories must also be heat-treated at certain temperatures. Probably many of the members had seen the symposium of papers that was read before the Faraday Society last November. It was suggested by the Council of that Society that, as refractory materials did not seem to have had much attention paid to them, the subject should be discussed before the Society. To his great surprise he found that a subject of national importance had been touched upon, and as a result nearly two dozen papers were forthcoming and about three hundred people were present at the meeting, showing that there was a great want of information on that particular subject. When he found the subject was considered of such great importance, he took the opportunity of bringing it before the Council of the Iron and Steel Institute. The latter decided to add a Refractories Committee to the various other committees formed, which he hoped now more generally represented the feeling of the members with regard to the nature of the work that the Institute should undertake. A number of other societies were asked if they were interested in the subject, and as a result a conference was held not long ago at which twelve societies were represented, showing that the subject of refractories concerned not merely one body but a very large number of technical and scientific societies. Whilst he was glad to see the representatives of twelve societies present at that meeting, he thought the Iron and Steel Institute ought to be predominant in the matter, because they were more largely interested than any other society.

He therefore hoped the industry would show its interest in the question by doing something definite. It would be very desirable that the members should support the Institute in spending a certain amount of money on research work, as the work could not be carried on without some expenditure, and a certain amount of secretarial and publishing work. He hoped that some day it would be possible to have the whole subject of refractories dealt with in a joint Journal. As the members probably knew, Dr. Mellor had done very good work in Staffordshire on the subject, and the Refractories Section of the Ceramic Society had been formed. The Iron and Steel Institute might enter into direct collaboration with them in their good work. Several of the members belonged to a large number of societies, but it was not possible for most of them to belong to more than two or three. A large number of papers which directly interested the Institute would probably be read before the Ceramic Society, and if there could be some interchange of information, and if the societies concerned could in some way come together, he thought it would be of the greatest benefit to the members interested in refractories.

Professor W. A. Bone, F.R.S. (Imperial College of Science and Technology), said he quite agreed with the author and Sir Robert Hadfield as to the great importance of the refractory materials question at the present juncture. It affected no industry or group of industries more than that which the Institute represented. Therefore the Institute ought to be able to work out the various problems connected with the subject, perhaps better than any other institution. He believed it was universally felt that scientists in this country had not given nearly as much attention to experimental research in refractory materials as they ought to have done.

The first item dealt with in the author's schedule was coke-ovens. Some ten years ago he (Professor Bone) had the privilege of being conducted over some of the larger coke-oven installations in Westphalia, and he was particularly struck by the amount of attention which was then being paid at Dahlhausen and elsewhere to the investigation of the materials used in the linings of the ovens. He could not help comparing the character and extent of the work that was going on there with the absence of anything comparable with it in this country. Two or three years later, when visiting America, he saw a little, though not as much as he would like to have done, of the work on refractories that was being carried out by American technologists. In connection with his own investigations upon the phenomenon of surface combustion, with its extremely high temperatures, he had received considerable help from the knowledge that American investigators had gained in respect of refractory materials. He had realised how the possibilities of "surface combustion" as applied to furnaces were limited only by the character of the available refractory materials, and he had formed the conviction that "refractories" constituted a most important field

of technical research which needed systematic exploration on new lines. He agreed with Sir Robert Hadfield that one of the good things that might transpire from the war was the enforced attention that would be given to the subject. At the Imperial College his colleague Mr. Hancock and himself had, at the request of the Institute, made a beginning with work upon materials for coke-oven linings and firebricks. That work was being pushed on as rapidly as the resources in materials, equipment, and men would allow. He would leave Mr. Hancock to describe the details, but there were one or two points of general interest that he desired to refer to. The first was the enormous variety of the problems which would have to be undertaken in connection with any really systematic research on refractory materials. That variety was so great that he thought it must be admitted that no single institution, much less a single person, could possibly deal with the problems adequately. Research would ultimately have to be organised on an extensive scale. The resources which were at present available in the country for that kind of work were very slender, and it was therefore all the more necessary to enlist the aid of all competent workers, and all laboratories that were sufficiently equipped to undertake it. He hoped the first business of any committee that was formed for the purpose would be to ascertain what were the facilities in existing laboratories and what people were competent, both by their knowledge and by the amount of time which they could give to it, to undertake such work. In the second place, work of that kind could not be carried on without a very considerable expenditure of money. He desired to put it to the great industry which the Institute represented, whose products he supposed could in normal times be valued at anything from £50,000,000 to £100,000,000 a year, that the financial provision for such investigations ought to be met very largely by the industry itself. He therefore appealed to all those large manufacturing concerns which used refractory materials daily, and the success and the improvement of whose processes would in the future depend very largely on the advances which were made in the investigation, to support liberally the fund which it would be necessary to raise for the carrying out of the research. He also desired to suggest that when committees were formed the people who were actually doing the work should not be excluded, as they too often were. The subject was one in regard to which he thought it was necessary to form committees, because work would have to be done in several places and by many people. He was not, however, altogether in love with Research Committees. They were doubtless useful for collecting suggestions and co-ordinating work, but they were not fruitful in originating ideas. The ideas generally originated individually with the workers themselves, stimulated by such discussions as they were able to have when they met together. Therefore one of the most useful functions a committee could discharge was that it should provide opportunities for the workers meeting from time

to time for the purpose of discussing informally, and without the presence of reporters, the problems on which they were engaged. In his opinion it would be extremely unfortunate if the committee that was appointed was made too small or too exclusive. He believed in Research Committees being fairly large, and of such a size that they were representative of all the important workers that were engaged, because the committee should not only organise, but it should also stimulate inquiry, and be the means of an informal exchange of ideas.

Some of the problems which the author had foreshadowed in his paper they were hardly yet in a position to take up. The author had asked for criticism and, although he (Professor Bone) did not wish to go into detail, there was one thing the author mentioned to which he had to take exception. Mr. Johns had stated that he thought the question of the thermal conductivity of refractory materials would be a very easy problem. Personally he could not see that it was going to be at all an easy problem. Some years ago, in connection with a certain technical problem, he had endeavoured to determine the increase in thermal conductivity of a certain refractory material at temperatures between about 500° C. and 900° C., and although he had at his disposal the resources of a very well-equipped laboratory, especially in regard to its pyrometric instruments, he found it was an unusually difficult problem to investigate. He formed the conviction at the time that an investigation of the thermal conductivity of refractory materials at such temperatures as 1000° to 1200° C. would be a problem of extraordinary experimental difficulty. He did not think it was well to assume that the problems that had to be faced were going to be easy; they would require all the skill that the members could command, and many of them would entail long and difficult researches. He hoped, therefore, the difficulties would not be underrated. He would remind the meeting that a cognate institute, the Institution of Gas Engineers, had done a great deal of useful work in the way of improving the retorts used in gasworks. Some years ago a representative committee was appointed which had collected a great deal of information, and carried out experiments, the results of which, he believed, had led to the standardisation of a retort for British gasworks of a much improved calibre. He suggested that the Institute might take a leaf out of the book of the Institution of Gas Engineers and organise an investigation of the special problems of the iron and steel industries on somewhat similar lines.

Mr. James Dunnachie, Jun. (Glasgow), said the paper did not lend itself to controversy, but it had opened up a very wide field, and he wished to say that, as a manufacturer, he would most heartily co-operate with the users of refractories, and welcome the closest connection with the steel-makers. It was fair to say that when the manufacturer tried to bring out something better in firebricks, he did not meet with much support from the steelworks. His own

experience rather was that the steelworks tried to belittle what was brought out, so that the manufacturer did not have much satisfaction in producing something better. However, his firm at Glenboig were only too anxious to get together with the users and do all that was possible to make improvements. He would welcome a closer union between the manufacturers and the users, so that the results of the tests with experimental bricks might be verified by trials under working conditions in the furnace.

Dr. J. O. Arnold, F.R.S., Member of Council, congratulated the author on his most useful and suggestive paper. The time had come when it was necessary to speak out a little plainly. Twelve years ago his experience at the University of Sheffield in endeavouring to institute researches in refractory materials was not altogether a happy one. At that time they were putting down an experimental furnace, open-hearth, of about 2½ tons, and a friend of his, who knew Germany very well, said that the Yorkshire silica bricks were not so good as the German bricks, and that when the furnace was being lined a couple of square feet of some German bricks, which he would send, should be put in. That was done, and ten heats were taken out of the furnace, which was a very hot one, and after ten heats those bricks were standing out 2 inches as compared with what the author had mentioned of ½ inch. He sent for the local brick manufacturers of the silica bricks, and had a very warm time of it. He obtained the analysis of the German bricks and the structure and gave it to the manufacturers, and pointed out to them that the bricks contained only 92 per cent. of silica, and they said they would not go on to the market with such makes. He pointed out to them the bricks, and the fact that they were standing out 2 inches after ten heats while theirs had all gone back. He was told that he was unpatriotic, was attacked in the local papers, and had to give the thing up. He told the local brickmakers that, until they could produce bricks equal to the German bricks, with the chemical composition which they sneered at, he would line the whole of the furnaces in the University with German bricks. He did so, and had German bricks in all the furnaces for at least eighteen months, but at the end of that time, two British manufacturers, one in Sheffield and one away from Sheffield, challenged the German bricks, and he lined a Siemens crucible furnace in three layers, two with British bricks and a German brick, and gave them a very severe test, and they all came out equally. He pointed out to the silica brick manufacturers at that time that the chemical composition did not at all decide the quality of the silica brick, and that a grading of the particles of the ganister or siliceous material used was extremely important. The British manufacturers were obsessed with the idea of getting very large particles of ganister, but the German bricks were very much finer in texture and, though inferior in chemical composition, were superior in the furnace.

Since the commencement of the war a very large scheme of research had been arranged for at Sheffield University, and his experience in the University, which he claimed had been most closely in touch with steel metallurgy, was that it was necessary to separate research from teaching, and to have a research department apart from the teaching department for post-graduate work. The University had a scheme now before the Government which involved a capital expenditure of £30,000 and a revenue grant of about £3000 a year for research purposes, and that was still under discussion. The idea was that Sheffield should find half the £30,000 capital account, and the Government pound for pound. He had lately met the directors of Messrs. Hadfields, and pointed out that the University had already obtained £13,000 in Sheffield, and that before he approached the Government more closely he should like to be able to say that they had half the capital account ready. Quite unostentatiously the following morning Sir Robert Hadfield, on behalf of Hadfields Limited, gave him a cheque for £2000, because he had mentioned to Sir Robert that in the new research scheme a laboratory for refractory research was one of the main features. The subject of the paper was of such importance that it was possible to talk for an hour or two about it. The Sheffield University was fully alive to the importance of the matter, and he wished to utter a caution on the subject of refractories with regard to the great nonsense which was talked in text-books, nonsense which was doing a very great deal of harm. The melting point of a silica brick was something under 1500° C., and what he asked was, How on earth could the University and the works in Sheffield, as they all did, tap their open-hearth steel out at over 1600° C.—why were not the silica bricks melted in the bottom of the furnace? He thought the difficulty had arisen from the fact that the text-books were recording the softening point of the bricks, which could be got to soften at 1450°. He sincerely congratulated the author on his very valuable and suggestive paper, and could only say that, so far as those in the Sheffield University were concerned, they agreed with almost everything which the author had suggested, and they would do everything possible to help the iron and steel industry in general, and the Iron and Steel Institute in particular, in connection with the matter.

Mr. H. M. Ridge (London) said his experience had been that, while the British clays were in no way inferior to those obtainable on the Continent, they had not been used in the past to the best advantage, and the Germans, who had gone into the matter most thoroughly, really treated not only their best clays scientifically, but also worked up their inferior clays and made good bricks with them. In that connection he would like to instance the work done by Schwerin in Germany, who showed and proved, by actual demonstration on a commercial scale, that it was quite feasible to eliminate many ordinary

impurities from the clay and make good quality articles, although the raw materials in the first place had been unsuitable for making a high-class brick. Works were to have been erected in England, but unfortunately they had not been built owing to the war. If Sheffield University or any other body was going to carry out research work, he thought the osmose process could be very usefully followed up, because, amongst other things, it had been found possible to remove almost entirely the alkalies from the fireclay, and as those played an important part in reducing the fusing point and the softening point of the firebrick, their removal was of great importance. Krupp had installed a complete osmose plant and had materially improved their product. He should like to mention one particular clay deposit in Austria, about which little had been heard in England, although it played an important part in German firebrick manufacture, and especially in making retorts, namely, the fireclay from Briesen. That material was neither highly plastic, nor would it apparently lend itself to firebrick manufacture, but some forty or fifty years ago it was found that the addition, depending on the nature of the clays used, of from 5 to 10 per cent. of the material had most extraordinary effects on the quality and the refractoriness of the firebrick. It appeared to retard the molecular rearrangement of the various minerals under heat. It had been used quite extensively in steelworks and in connection with coke-oven bricks, zinc retorts, glass-house pots, and similar purposes, although, as it contained some 38 to 39 per cent. of alumina, it could only be used to advantage in high alumina brick. Certainly it considerably raised the softening and melting points of the brick, and increased its resistance to the attack of iron sulphide and molten metal. Another material of which considerable quantities had been used in Germany was kaolin from Bohemia. That kaolin could be found in most of the large and better class firebrick works right throughout Germany even into Westphalia. The Bohemian kaolin would stand up to Seger cone 36, and also went a long way to assist in improving the quality of the firebrick into whose composition it entered. The Germans not only carried out careful experiments to find out the maximum quantity of burnt fireclay or grog which could be put into the brick, but also to determine the best size of the particles of the grog for the bricks to be used for special purposes. Germany had insufficient suitable material for burning to a good grog which would not shrink in the furnace after having been put into permanent use, and consequently they had to import shale from Scandinavia in shiploads for that purpose. He had found Scandinavian shale in use on the Rhine, and as far east as Upper Silesia, where it had to be taken not only by water, but eighty or more miles by rail in addition. He would like to say something about the firebrick which could be obtained from the makers in this country. Personally, he had a great deal of difficulty in obtaining from the various makers a continuous supply of suitable and well-burnt firebrick. Only recently while visiting some

new furnaces he found one which was only being heated up and already showed distinct signs of shrinking, so that it had cracked right through to the outside. He examined some other furnaces as well as the stock of firebricks that had been delivered for use, and he found that a large percentage of the firebricks which had come in from some well-known makers had been very imperfectly burnt; in other words, they were bound to shrink as soon as they were heated up in the furnace. That was something which the rational use of the pyrometer at the kiln would easily overcome. On the other hand the user ought also to look after his own interests after the bricks had been despatched from the makers' works. Unfortunately, in travelling about the country, it was possible to see everywhere open railway trucks loaded with firebricks, and the question arose whether that was a reasonable treatment for good quality materials. Personally he doubted it. The trucks carrying good firebricks should be sheeted and the bricks protected from the weather. In some works it was possible to see stores of firebricks stacked in the open. He would not mention silica bricks in that connection, because it would obviously be disastrous to store them in that way. It certainly was not reasonable, after exposure to the weather, to put any firebricks into a furnace and heat them up quickly. More care and attention to that matter would be of material assistance. In Germany the makers of good quality firebricks had been prepared to quote for and sell firebricks on the basis of an average analysis, maximum expansion, and temperature at which softening would commence, in addition to stating to what temperature the bricks were burnt in the kiln; they also undertook to supply bricks true to shape with a maximum variation of plus or minus 2 per cent. in any dimension. If British firebrick manufacturers could be induced to do something similar, it would be a very great benefit to the whole of the metallurgical industries. He had not yet been able to find a place in the country to which he could send single whole firebricks for proper scientific testing. He had raised the point at one or two other meetings in the past, and at one of the meetings a laboratory apparatus was shown in which a small cylinder could be tested, 2 inches long by $\frac{5}{8}$ inch diameter. The difficulty of preparing a cylinder of that size from a properly burnt firebrick was such that one was not going to take it as a test if one could avoid it. Secondly, the result would not always be in accordance with the result which would be obtained from testing a full-sized brick. He thought the interests of the members of the Iron and Steel Institute would be greatly served if it were possible to arrange in this country, comparatively soon—he did not mean in ten or twenty years' time—for a plant where proper tests could be made under heat with a $9 \times 4\frac{1}{2} \times 3$ inch firebrick. An interesting point had been raised as to the use of bricks both for heat conductivity and heat conservation, and unfortunately most people were in the disagreeable position of having to use the same brick for heat conductivity as they used for insulation, and that was another

case where a research laboratory would be a very great assistance. With regard to the points raised by the author, he would like to mention the Belgian silica material, fine silica sand obtainable from the Ardennes, in the same district from which the finely divided, highly plastic siliceous clay was obtained. If crucibles or retorts were made from it, surely that would transform the hexagonal quartz into tridymite. If the author could give any information on that question, it would be of interest. In connection with the manufacture of retorts, he personally had found a great difference in their life, depending not only upon the materials of which they were made, but specially on how the materials were treated in the course of manufacture. Hand-made retorts he found very much more porous than those which were pressed by a hydraulic press, and afterwards carefully and slowly dried. Also the material resisted the action of gases and of slag to a very much greater extent, and where it was required to resist both corrosion and erosion, he thought greater care in manufacturing the material and in drying and burning the brick would, without any alteration of the composition, very materially enhance its value.

Dr. J. O. Arnold said he had been asked to reply to one point raised by Mr. Ridge, namely, his demand for a practical furnace for testing bricks, a demand which was perfectly reasonable. There were two such furnaces at Sheffield. One was a 2½-ton Siemens furnace in which it was possible to get the bricks to a temperature of 1750° pyrometrically, and the other a crucible furnace which could go up to 1650°. At the present time there was a committee considering the question of using those furnaces for practical testing purposes, on which committee he was associated with his colleague, Professor Fearnsides, the Professor of Geology.

Mr. E. H. Saniter (Rotherham) said the paper was a very important one. The point in the discussion which had impressed him most was the emphasis that had been laid on the question of co-operation with other societies to cover this very wide subject. He felt that was very important, and he had been greatly pleased to hear that it was being pushed to such an extent. He would suggest that co-operation of the same description should be extended to the Refractories Committee formed by the Institute, and he would suggest that if any success was hoped for, it was necessary to bring in the manufacturers as well as the users.

With regard to magnesia bricks put down as being used for electrical furnaces, he might say that they were also very largely used in basic Siemens furnaces. In his opinion, the magnesia bricks made in this country were very inferior. He did not say that that was due to the fact that the bricks were not well burnt or well manufactured; he thought the manufacture started on a wrong basis. The subject should be very thoroughly investigated. His experience of magnesia

bricks extended over a great number of years, and that experience showed him that an iron bond was rather to be preferred than the bond used in English-made bricks. Bricks with 7 or 8 per cent. of iron oxide in them in his opinion were more satisfactory. He found that the bricks which were being made nowadays, after being subjected to heatings and coolings, very often went to powder. In that respect one might just as well ram the dolomite against the sides of the furnace as put such bricks there. He had had experience of iron bond in years gone by, and had found the bricks did not deteriorate in that way. Another point in connection with their composition was that it was entirely unnecessary to strive after a very high percentage of magnesia; they were absolutely sufficiently refractory with considerably less magnesia in them than was put in to-day. The question of the difficulty due to rapid changes of temperature was one that required investigation, and he believed had been lately investigated to a certain extent by Dr. Mellor of the Ceramic Society, which had now a refractory section. With reference to sand for open-hearth furnace bottoms, as far as he was personally concerned, he would not need to use any more Belgian sand at all. The bottoms of the furnaces of his firm were now made entirely from English sand, and they stood better than when Belgian sand was used. He did not think that was because the sand was English; he believed that when Belgian sand was available it was too refractory and was not let down to a sufficient extent to consolidate the furnace bottoms. If ever Belgian sand came into this country again, it would be wise to let it down with an inferior sand much more than had been done in the past. With regard to dolomite bricks, he did not see any difficulty in making such bricks just as magnesia bricks were made; the only objection was that the bricks could not be kept for more than about six weeks before they began to slack down. He believed that bricks were now being made by pressure from burnt dolomite and tar, and used without burning. There was no doubt that in the stress due to the war there had been some deterioration in silica bricks, but at the same time he thought the brickmakers had carried out their work very well, and that a good deal of thanks were due to them. He felt sure that research in that direction would enable them to improve their bricks in the future. The question of how much lime should be in a silica brick also seemed to be well worth further consideration. The bricks to which the author referred had 4 per cent. of lime, and yet they were standing up well. He himself had been trying a ganister mixture for laying silica bricks. The ganister contained only 92 per cent. of silica and he had added 10 per cent. of lime, and the joint had worn away evenly with the bricks. That seemed a very remarkable result. Mr. Walter Dixon had put him on the track of the matter, and he had been trying it.

Professor T. TURNER (Birmingham University) said he was very

glad that the question of refractories was being discussed by the Iron and Steel Institute. He had ventured on several previous occasions in connection with Institute meetings to point out how on the Continent and in America scientific experiment and tests of refractories were far more carefully carried out and far better developed than they were in Great Britain. As a result, no doubt, of the present necessities, there was a wave of interest rolling over the country on the subject, and it should not be allowed to be temporary. A good deal of pioneer work would have to be done in the scientific investigation of the subject, which was a wide one, and could be approached either from the research point of view or from the small manufacturer's point of view, as the case might be. As had been already said, from the scientific research aspect a combination would be required of all the facilities the country could afford. Many of the investigations required apparatus of great accuracy and the devotion of much time Some operations alone would take many days. It was gratifying to know that in Great Britain there were, in institutions connected with the larger technical colleges and universities, appliances with which the work could be done, but those appliances would, of course, require considerable development in the immediate future. The ordinary manufacturer was liable to feel somewhat appalled when he heard of the kind of test to which it was proposed to subject his material. Coming from a district where there were over a hundred firms engaged in the refractory industry, he could say that at least half of them had no system of testing at all, except the practical test that the product, on being sold to the customer, either did or did not suit him. He thought that throughout the country generally it would be found that a very large number of the firebrick manufacturers had made no attempt at quantitative expressions of the quality of their material; the clay was said to be good, it was refractory, it was bad, it was plastic, and so forth; but they did not attempt to compare one clay with another, for instance, with reference to its plasticity by means of numbers; and until they did that numerically and kept records they had nothing to which they could authoritatively refer. If a committee was formed on the subject of refractories he hoped they would keep in view what he had called the pioneer work in connection with manufacture. In steelworks there were tests that could be applied in half an hour or less to show whether or not the material was suitable for its purpose. There were a number of tests which could be done by comparatively unskilled labour and done at least in one day, as for instance porosity, plasticity, shrinkage, and tenacity; while with simple methods, such as the use of the Seger cone, the softening point temperature could readily be determined. It should not be difficult for a small manufacturer to take a young man who had been attending a technical school—in the way that had been done in many cases in steelworks in connection with chemical tests—and that young man, at a comparatively moderate salary, could start with simple tests in a small room,

and in that way the manufacturer could begin to build up a laboratory. If it were suggested to the manufacturer that he must have very expensive apparatus and highly skilled men with which to start, he would never, probably, get a laboratory at all. Clay pits and clay works were in the hands of so many relatively small firms and on such a small scale—although the aggregate product was large—that it was necessary to introduce science for practical purposes from the bottom, and allow it to be extended or increased as its value was shown. It was not suggested, however, that that was all. Every one fully recognised the great importance of the highest research by the most accurate means, and that such research involved money and very high training. A local manufacturer might, for instance, be asked for a chemical analysis. It would be absurd for him, in a small place, to have a chemical laboratory and a man sufficiently skilled to do a complete analysis when an analysis was only required occasionally; it paid him far better to put the analysis out to a qualified man. But the other tests ought to be done every day and recorded regularly, and on the basis of such tests the manufacturer should be able to supply material of better conductivity or less conductivity or more shrinkage or less shrinkage, as the case may be.

He believed in attending to both ends of the scale, just as was done in ordinary education; elementary education being the basis of higher education, and higher education leading to the improvement of elementary; so, as science was developed in connection with the industry the small manufacturer should not be forgotten and he should be led to interest himself in the work.

Dr. W. Rosenhain, F.R.S. (National Physical Laboratory), thought it was only fair, in justice to the Institution to which he belonged, that he should say a word or two as to the work on refractories which had been done and was being done there in its earlier stages, particularly by his colleague, Dr. J. A. Harker, F.R.S. His reason for referring to that work lay partly in the remarks made by Mr. Ridge as to the difficulty of getting certain tests made. It was quite true, he thought, that there was probably not in this country at the present moment a furnace in which a whole firebrick could be melted and its fusing temperature determined, but he ventured to think that was not necessary. The kind of test to which Dr. Arnold referred, in which one face of the brick could be exposed to a high temperature, but below its melting temperature, was a practical kind of test which was available in several places, in the metallurgical laboratory at the National Physical Laboratory as well as in Dr. Arnold's laboratory, but it was not everything, and he thought that the other test, which consisted in determining the collapsing pressure under a given temperature or, better still, the collapsing temperature under a given pressure, of a small piece cut from a brick, was really in the end a sounder test of the quality of the material. It involved

a little trouble in cutting a test-piece, but that trouble was not nearly so great as Mr. Ridge's remarks would lead one to believe. There were several directions in which the work which had been going on for a good many years at Teddington bore on the subject of refractories. First of all with regard to pyrometry it was of vital importance to the manufacturer and to the user of refractories to know that a very large amount of work had been done and was being done day by day in the standardising and testing of pyrometers, and that work should be borne in mind. Beyond that, the question of the testing of refractories had received a large amount of attention, and at the present time the Laboratory was engaged on a whole series of researches on refractories, which were hampered for the moment by insufficiency of equipment, but that insufficiency it was hoped would be made good shortly. Steps for improving it were being taken now, and it was hoped that support would be given to enable the Laboratory to improve it to the extent which was obviously necessary. The aspect of the subject, so far as the paper was concerned, which most appealed to him personally was that group of refractories which the author referred to as special, zirconia, bauxite, carborundum, and so on. It was quite true that many of those materials at present were not in practical use on a large scale in the iron and steel industry, or indeed in any of the large industries, but he would put in a strong plea for the point of view of not looking merely to meeting the practical requirements of the moment as seen by experts or a committee of users and manufacturers, because to limit efforts in that way was to limit the service that could be rendered. It was necessary to look forward to things which would not only enable people to do what they wanted to-day but which would show them what it would be possible to do to-morrow. It was necessary to think broadly and for the future in planning out any scheme of research. He sympathised with the remarks of Dr. Bone as to the limitations of Research Committees; they were very excellent things, but they must above all give the research worker the freest possible hand, otherwise their efforts would not be as fruitful as they might be. That was particularly so in regard to the subject of refractories. The special refractories were, he thought, things of the future. If one looked into the whole history of metallurgy one would find the tendency had been for a steady progress in the direction of higher temperatures. The electric furnace, which was the latest development in steel metallurgy, certainly involved higher temperatures than were ever used practically in industries before its advent, and the whole possibility of future development might lie in the direction of still higher temperatures, and for that purpose dependence would have to be placed on better refractories than any that had been at the disposal of manufacturers before or than anything that could be mentioned at the moment. For that reason he pleaded strongly for the importance, particularly, of the last item in the author's schedule, which he was

glad to hear was one of the items which he had starred for special attention.

Mr. W. C. Hancock (Imperial College of Science and Technology) said it was very gratifying that the subject of refractories was at last beginning to attract the attention which it deserved. Few people, he thought, had realised that there was no manufactured product on the world's markets which was not ultimately, at some stage of its production, dependent on a refractory material. But in common justice to many workers in that extensive field, it was necessary to remember that the study of refractory materials did not date from about August 1914; a very large amount of work was done a good many years ago both in Germany and in the United States. In this country, unfortunately, the idea was prevalent that the ultimate chemical analysis of a refractory material was all that was required to arrive at some definite conclusion as to its qualities. Later experience had demonstrated that that was entirely fallacious. It was the physical properties of the materials which ultimately determined their value in actual practice. He believed that some of the earliest records of the physical testing of a series of English clays were the results published some eight or nine years ago by the Geological Surveys, and one had also to remember a point Dr. Rosenhain had emphasised—the valuable work which had been done at the National Physical Laboratory, the excellent work of Dr. Harker, for example, and also the work of Dr. Mellor, and workers in a good many other places where refractories had been the subject of investigation. As the time was extremely limited he could only refer briefly to one or two of the interesting points the author had brought forward in his paper. The author seemed to have been somewhat troubled that at the present time there was no other definition of refractories than that which he had been good enough to give in his paper. But there was no need to worry about that. Probably, as had been said, the last definition in physics which would ever be given was that of matter itself, the subject of the whole science. But it might be taken that the qualities required in actual practice were fairly well known, and therefore there was no need to worry about a definition of a refractory. He was glad the author had drawn special attention to the subject of texture. In some research work into refractories required for coke-oven construction, which he had had the honour of carrying out recently at the Imperial College of Science, under the direction of Professor Bone, he had paid particular attention to that point. It was perfectly easy of course to obtain the texture of the raw, unfired clay materials, but what was wanted was the texture and structure of the actual fired material as it came into use. That was an extremely difficult problem. No method of disintegration would be possible, because by disintegration a great deal of the structure was destroyed owing to the hardness of the material. It would seem the only possible channels of attack were either by means of thin

sections as in petrography, or by polished surfaces as used in metallography. The importance of texture was very great on account of the influence which it exerted first of all on the resistance to sudden changes of temperature, on the porosity of the material—using that word, by the way, as meaning the total amount of pore space—on permeability, which should be stated whether to liquids or to gases, and on many other qualities. Another important point to which the author had referred was that of abrasion, on which very little work had been done. A specification was given some time ago of a method which was described as a "rattler" test, which merely consisted of placing test-pieces in a closed cylinder, the dimensions of which were rigorously given, together with a certain number of balls, the composition of which was also specified, even, he believed, the silicon and phosphorus contents, and the whole apparatus was closed up and turned; in other words, the test-pieces were subjected to the action of a modified ball-mill, and in consequence it was a measurement of resistance to a series of impacts and not to actual abrasion. As in the course of his investigations on coke-oven refractories, abrasion seemed to be a point well worth investigation, they had lately devised at the Imperial College a very simple form of apparatus which enabled measurements to be obtained of the action that went on. By a simple arrangement two test-pieces were superimposed, the lower being held firm and the upper one made to pass backwards and forwards over the lower by an arm connected with an eccentric and driven by an electric motor. The apparatus could be arranged in such a way that the test-pieces could be easily included in a furnace, so that it was perfectly possible to get abrasion tests with comparative ease at working temperatures, though he had not, for obvious reasons, made a very large number of experiments with the apparatus at high temperatures. An important point first of all was to determine whether the method seemed to be sufficiently reliable to justify the further use of it. From the number of observations that had been collected, it would be quite unsafe to draw anything like general conclusions. The only two or three points which appeared from the preliminary experiments to come out were, first, that the actual abrasion by one clay surface upon another was least with fine-grained material; secondly, that the materials at ordinary temperatures were abraded, unfortunately, to a very much less extent than they were at the higher temperatures. He cordially agreed with Dr. Bone that the determining of the heat conductivity of refractory materials at anything like working temperatures—and determination at ordinary temperatures might be regarded as practically useless—was a matter of extraordinary experimental difficulty. With regard to the research on refractories as a whole, he would cordially support all attempts at co-ordination and co-operation between the various societies, universities, and institutes concerned, for the amount of work involved was enormous. As an example he might perhaps mention that on a series of some twenty-five test-

pieces in connection with porosity and shrinkage and the effect of various amounts of grog added to the clay, his assistant made something like 2500 observations.

CORRESPONDENCE.

Professor HENRY LOUIS (Newcastle-on-Tyne) desired to draw especial attention to the value of zirconia as a refractory material. Whilst its high cost would probably render it difficult of use in ordinary furnace work, it promised to be extremely valuable in special work at high temperatures, and more particularly as a lining for electric furnaces. He had been experimenting recently in that direction, and had succeeded in finding a binding material which promised highly satisfactory results. Supplies of commercial zirconia (baddeleyite) had hitherto been obtained only from Brazil; it usually contained 70 per cent. to 75 per cent. of zirconia, about 10 per cent. of silica, and a considerable proportion of iron. He had been experimenting with zircon, a silicate of zirconia, containing usually just over 60 per cent. of zirconia, a sample of which was kindly supplied to him by the Imperial Institute for experimental purposes; this mineral was widely distributed and occurred, amongst other places, in various parts of our own Empire. Its price was about a fourth or a fifth of that of commercial zirconia, so that it was a much cheaper article to use. It was remarkably indifferent to the action of alkaline fluxes, and certainly stood a high temperature, though he had not yet finally determined how it compared with commercial zirconia as regards fusibility. It possessed one very great advantage over zirconia, inasmuch as the latter shrunk very considerably on heating, whilst the shrinkage of zircon appeared to be negligible. The main difficulty he had met with lay in its highly crystalline structure, which made it more difficult to work into bricks, &c., than zirconia. He had, however, been experimenting with the same binder as he had used for zirconia, and the experiments so far promised very well; it required, however, to be burnt at a temperature of 1200° C.

Mr. COSMO JOHNS wrote in reply that he gratefully acknowledged the kindness with which the paper was received. The efforts of Sir Robert Hadfield to co-ordinate the work of the many societies and institutions interested in furthering research on refractory materials should have the result of establishing research on broad lines in this country, and thus rendering more completely available the rich store of raw material existing in these islands. The approval of the Master Cutler of Sheffield was noteworthy, representing as he does a district where, owing to rapid advances in metallurgical practice, many of the problems discussed in the paper have become urgent and demand

attention. He thanked Professor Bone and Mr. Hancock for directing attention to the experimental difficulties experienced in determining the thermal conductivity of refractory materials at high temperatures. Possibly the magnitude of the problem would be reduced if determinations at service temperatures only were attempted at present. He (Mr. Johns), so far from underrating the difficulties of research, had striven, as far as possible, to direct attention to the present lack of experimental data, the difficulty in determining the physical constants and the physico-chemical relations of the materials used in practice, and the need for experimental work of a high degree of accuracy. Mr. Dunnachie probably represented the feelings of many other leading manufacturers in offering to co-operate with the users of refractory materials. Cordial and intelligent co-operation between makers and users would be a most important factor in effecting those improvements in quality which were so urgently demanded. It was interesting to learn from Professor Arnold that a department of refractories was being organised in the University of Sheffield on a scale commensurate with the importance of the area served. The important communication by Mr. Ridge drew attention to the lack of interest formerly exhibited in this country in the methods that recent advances in physical chemistry have rendered available for the purification and concentration of the raw materials of the refractories industry. The osmose process for eliminating impurities from clay was reported to have been tried on a small scale in this country and discarded. That it should be investigated and its possibilities determined was a matter of urgent necessity, and he (Mr. Johns) agreed with Mr. Ridge that it should be taken up. He would further urge that an investigation into the problem of eliminating lime from the dolomite found so extensively in this country should be carried out, thus enabling the remaining magnesia to be used for magnesite bricks. The impurities found in the dolomite would, when concentrated in the magnesia, approximate to those found in Styrian magnesite, which was probably formed by the decalcification of an original dolomite. He (Mr. Johns) hoped that the efforts that were being made to co-ordinate research in this country would result in attention being given to many of the problems suggested by Mr. Ridge. He thanked Mr. Saniter for his contribution to the discussion. There was no doubt that English makers had overlooked the influence of iron oxide as a bond for magnesia and the importance of firing at a high temperature. There was reason to believe that attention was now being directed to these points. It was significant that the virtue of Styrian magnesite was in its impurities. He agreed that we had in this country silica sands of good quality suitable for the hearths of acid open-hearth furnaces. He thanked Dr. Rosenhain for his interesting account of the work in progress in the Department of Metallurgy at the National Physical Laboratory. The special qualities of the rarer refractory materials had drawn attention to the possibility of using them on a commercial

scale in high temperature metallurgical work. Any addition to our knowledge of the methods of purification and preparing them in useful forms would be beneficial even if their application were only on a limited scale. In reply to Mr. Hancock he (Mr. Johns) still thought it desirable to define "refractory materials," and seeing that no criticism had been directed to the one given it might stand so far as the metallurgical industries were concerned. He was glad that so much useful work was in progress at the Imperial College of Science and Technology. The great difficulty at present was working out the best experimental methods for determining in terms of precision the qualities or properties sought for in refractory products. The resistance to abrasion at high temperatures of a mineral aggregate such as a coke-oven brick suggested such difficulties in determination that it was encouraging to hear that so much progress had been made. In the case of the smooth face of a simple crystal the resistance to abrasion was a measure of hardness. The superior resistance of the fine-grained samples in Mr. Hancock's experiments was not altogether unexpected. The experiments of Professor Louis with zircon in place of the rarer zirconia were most interesting. A very valuable addition to the list of the rarer refractories will have been made if another zirconium compound, more widely distributed than baddeleyite, could be rendered available.

No discussion of refractories would be complete without a reference to the use of metallic alloys whose particular properties render them valuable as refractory materials. Certain alloys, with chromium as a dominant constituent, possessing considerable mechanical strength and retaining the high degree of thermal conductivity that characterised the metals, could be subjected to temperatures in the neighbourhood of 1000° C. under oxidising conditions without deterioration. The significance of this could hardly be overestimated. Certain alloys of titanium and iron were insoluble in molten steel, and had a melting point certainly higher than 1600° C., and probably near 1850° C. The possibilities of titanium alloys as refractory material were thus strongly suggested. There was little reason to doubt that an investigation of the metallic alloys mentioned, and of others that might suggest themselves, with a view of determining their properties as refractory materials could not fail to furnish results of far-reaching significance.

STEEL INGOT DEFECTS.

By J. N. KILBY (Sheffield).

The paper submitted to this Institute by the author in September 1916 was, as stated, purely introductory. Embracing, as the subject does, such a wide and varied field, it calls for due consideration of individual works, circumstances, and class of material desired. Hard and fast lines may be difficult to adhere to strictly, modifications being necessitated by the conditions of the particular branches of the industry. These modifications may not influence the actual principle of any process in the main, yet they may be essential to its ultimate success. In spite of variations met with due to the different conditions there exists a necessity that the system proper which is applicable to all works conditions should be standardised. A good many of the methods of manufacture have probably arisen from one or more of the following causes:

(*a.*) Lack of interchange between departments of opinion and investigations upon failures or defects.
(*b.*) Lack of interchange of ideas between different works.
(*c.*) Through obviating defects peculiar to the individual works, due to local or other isolated conditions.
(*d.*) Increase of output without full regard to conditions ruling quality.

Ingots of Three Tons and Under.

A good percentage of the defects in steel ingots come under the following heads:

Pipe, Segregation.
"Occluded slag."
Fluxed fireclay (occluded).
"Lappiness."
Cracks.

Pipe.—A given volume of similar liquid steel will, under like conditions, solidify with a definite amount of, or volume of, shrinkage.

The receptacle into which the steel is cast governs the position in the ingot of the pipe cavities, and therefore the amount of the ingot which it is necessary to discard for the production of sound steel (Fig. 1, *a* and *b*).

Fluctuations in casting temperature, rate and method of

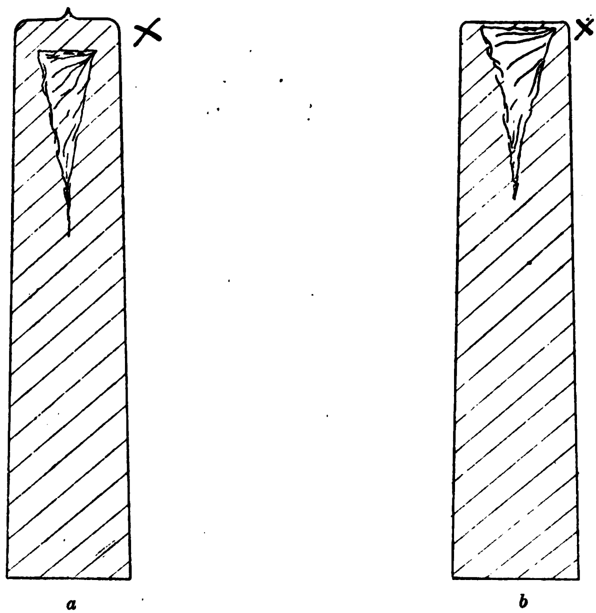
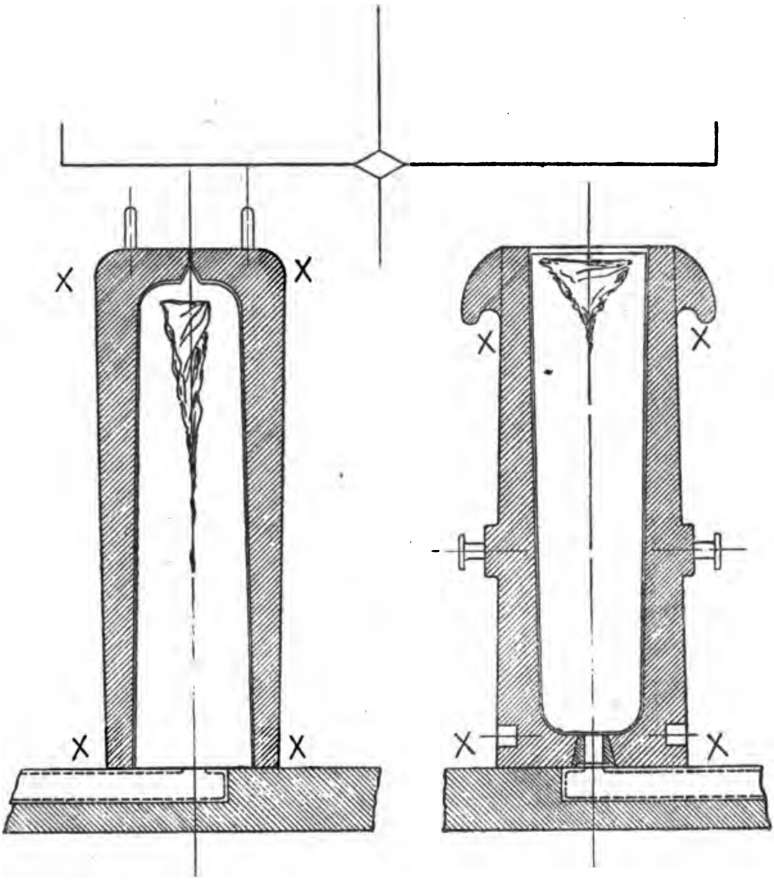


FIG. 1.—Both ingots narrow end up. (*a*) closed top. (*b*) open top. Showing difference in thickness of the top of the ingot.

teeming, percentages of silicon, manganese, and aluminium influence the pipe more or less according to the type of moulds used.

Messrs. Brearley, in their admirable paper of September 1916, more than emphasise the important relationship between mould type and pipe, and leave little room or necessity to expand upon this particular point. It was a curious coincidence that the author has also dealt with the same subject, and whilst not upon exactly the same lines, yet having a similar object in view. The sketches of ingots showing pipe in his introductory paper were

based upon the establishment of the central run mould by the orginators of this type. Steelmakers, after thorough investigation,



A (old type).—Bottom-cast, closed top. Narrow end up.

B.—Bottom-cast, open top. Wide end up.

FIG. 2.—Showing relative thickness of mould at top and bottom and comparative "XXXX" influences upon solidification.

must accept the mould with the wide end up as the one conducive to minimum pipe. The longer the ingot in proportion to its cross-sectional area the worse the trouble with the old narrow end up type (see Fig. 3). Mould type, and method of casting,

should be made one of the most important points of steel specification.

The use of the old type mould, Fig. 2, A (with which should be coupled types A, F, and G in the author's introductory paper), is still part of the standard practice in a good many works.

It would be interesting to have some discussion upon this point, obtaining the views of those who adhere to this class of

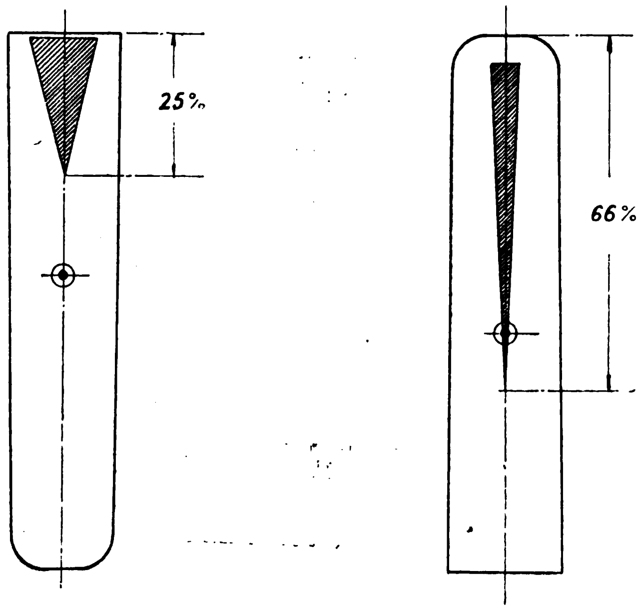


Fig. 3.—The centre of volume in two ingots same size but of both types, also the position of the pipe cavities given as equal, and based upon actual ingots, showing amount of ingot susceptible to pipe influences.

mould. With the exception of giving the pitmen and cranemen a fairly easy time there does not appear a single point in its favour. One of the greatest objections to the "new mould" in its earlier days was based upon the fact of its causing exceptionally heavy and more exacting pit work.

Fig. 4, showing an old type ingot forged down, explains the old assumption of being able to produce "perfectly solid" ingots.

After the question of mould type, one has to consider the necessity of using a feeder head and type of the same.

Except with special steels, the use of a refractory feeder head

has not been widely adopted. That it is necessary to produce the maximum of sound steel is beyond dispute. The type of feeder head does not matter a great deal, inasmuch as reducing pipe is concerned, provided it is of sufficient capacity adequately to feed the chill portion.

Quoting from Messrs. Brearley's paper of September last: "In producing steel at what is called the 'market' price these 'insignificant' defects are made as harmless as possible." Setting

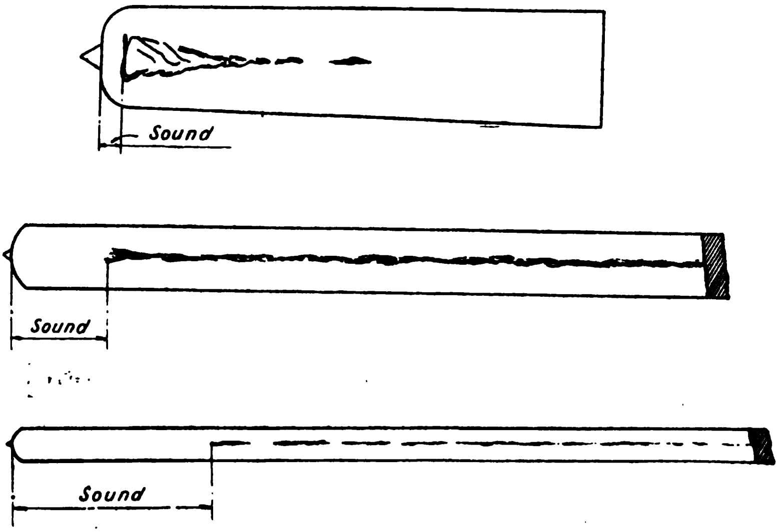


FIG. 4.—Showing old type ingot forged down to bars and indicating the "solid" portion at the top end of the bar, which misleads the forgeman on this class of ingot.

aside the question as to whether these defects are in any way detrimental to these particular classes of steel or not, there remains the factor of cost of production, which appears to be the real basis for not using heads more generally, or in other words, the extra cost incurred by the use of a feeder head would not be more than covered by the saving of steel. Let us see whether this is so or not.

The cost of production turns upon how much of the piped portion of the "unfed" ingot is utilised as saleable steel, against the cost of the feeder head and its gain in yield. The cost of a

feeder head per ton of steel varies greatly according to size of ingot and also according to type of head used.

The figures and details below are from actual works costs, and based upon piping steels of 0·45 per cent. carbon.

Ingot without Feeder Head.	Ingot with Feeder Head.
Yields 65 per cent. sound „ 15 „ doubtful „ 20 „ scrap	90 per cent. sound steel 10 „ scrap

We have therefore an increased yield of 10 per cent. for the cost of the feeder head, not considering the 15 per cent. doubtful material used as sound.

Ingot.	Would yield	At a Cost of
15 cwt.	1·5 cwts. more sound steel with head	1s.
20 „	2·0 „ „ „	1s. 2d.
30 „	3·0 „ „ „	1s. 4d.
40 „	4·0 „ „ „	1s. 6d.
50 „	5·0 „ „ „	1s. 8d.

Apart from the increased yield and more reliable steel, there is the great saving in the ultimate manipulation of the ingot in the rolling-mills, &c.

It would appear therefore that feeder heads are economically essential even for what is termed the "ordinary" steels.

Occluded Slag. Acid Open-Hearth.—Any oxide of iron admixed in steel exerts itself to a great degree upon the silicon and manganese additions just prior to tapping, and upon the aluminium after tapping, forming particles of "slag." Whether these particles remain evenly disseminated throughout the mass, or whether they partly or wholly collect and rise to the surface in the slag, is a matter governed by circumstances, and overshadowed by a good deal of doubt. As is well known, alloy steels and special carbon steels will not give maximum physical tests if not "free" from such admixture. The author is referring to steel which was supposed to have been "well melted" and worked throughout and given correct finishing conditions. The presence in ordinary carbon steels of this finely divided or emulsified

solution of slag is just as little desired as in the case of special steels, although not so liable to influence the ordinary physical tests called for in these steels. The author contends there are two sources whereby "oxides" may be taken and retained in the steel, viz.:

1. That formed during melting of the charge and not subsequently removed.
2. That introduced by excessive or erratic feeding of ore.

In the author's opinion the first essential in acid open-hearth manufacture should be the one of correct and consistent conditions at the melted stage. A good deal of importance is rightly placed upon the finishing conditions of the steel, and as these conditions are in sequence to the conditions at melting, and to a great extent governed by the latter, too much stress cannot be laid upon early stages of the heat.

A charge going to boil by virtue of the oxide formed during the melting down stage is, to say the least, not conducive to yielding a steel anything like free of oxides and slag inclusions. No matter what subsequent method of deoxidation be resorted to, the author contends there is great danger of a significant residual portion. A furnace working badly, such as at the end of a campaign where a record run may be being sought after, gives just that state of bath referred to. Slowly and cold melted charges are always highly charged with oxide. In these days of increased output and pressure upon furnace conditions and the usage of large proportions of the poorer grades of scrap, the presence of the evil is more likely to crop up than where output is of secondary importance given other conditions as equal.

The working of many and particular brands of iron in one charge had its basis of advantage unconsciously built upon silicon content, yielding regular and nearly accurate bath conditions at melting.

The two important factors up to the "melted" stage are:

1. Quick melting.
2. Correct state of slag and bath at melting.

The author has found that a 2·00 per cent. silicon basis is a good one to work to. By this is meant that the whole charge should have an available silicon content of 2·00 per cent., taking

the silicon in the pig iron, and making the difference up by adding slag in with the charge; for example:

50-ton Charge.

20 tons pig iron	1·90 per cent. silicon,
30 tons scrap	0·10 ,, ,,
	= 0·80 ,, silicon average,

which requires 1·20 per cent. silicon, adding in the form of slag, which works out at approximately 43 cwt. The use of slag in the charge reduces the amount of oxidation greatly, and gives more reliable bath conditions.

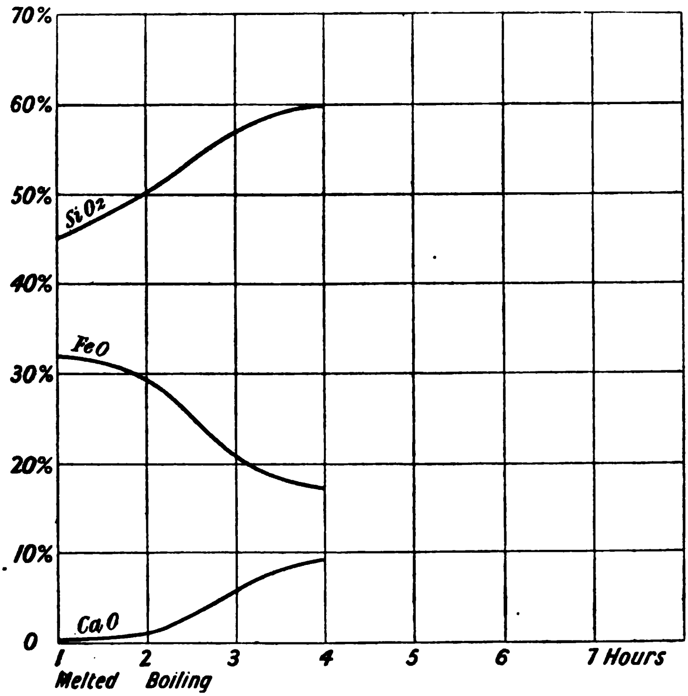
The melting of the charge is a strongly oxidising period, and, as previously stated, the question of what becomes of the whole of such oxide formed is a highly important one. It may be argued chemically that: "Any oxide formed must naturally be reduced by carbon, silicon, and manganese in the pig iron, in contact with which the reaction would appear inevitable."

Granted, that if the correct excess of these elements was available and the conditions were suitable, the reaction as stated above would probably occur, but an acid charge in reaching the melted condition does not exhibit much sign of either violent or a milder reaction, nor does it give the impression of freeing itself energetically from oxide. It is fair to assume that, the higher the carbon and the greater the "residual" silicon at melting, the less the opportunity for oxide retention, also that charges requiring little or no ore to work them must be in a highly receptive state for oxide.

It is well understood that the furnace banks and bottom suffer most after heats taking little ore. One can explain why only that part of the banks which is in immediate contact with the slag should be "cut" or fluxed away, but this explanation does not apply to the wear of the bottom. May it not be, under certain conditions of slag bath and temperature, that the metal holding these aforementioned oxides of iron is continually feeding upon the furnace hearth and producing particles of "slag," and the subsequent working is only partially removing the "slag" thus formed.

Effects of Limestone. Acid Open-Hearth.—The use of limestone in the acid open-hearth process is one of the greatest importance, as also the period at which additions should be made.

Charts I., II., III., and IV. (Figs. 5 to 8) give some idea of the influence of limestone upon the chemical composition of the



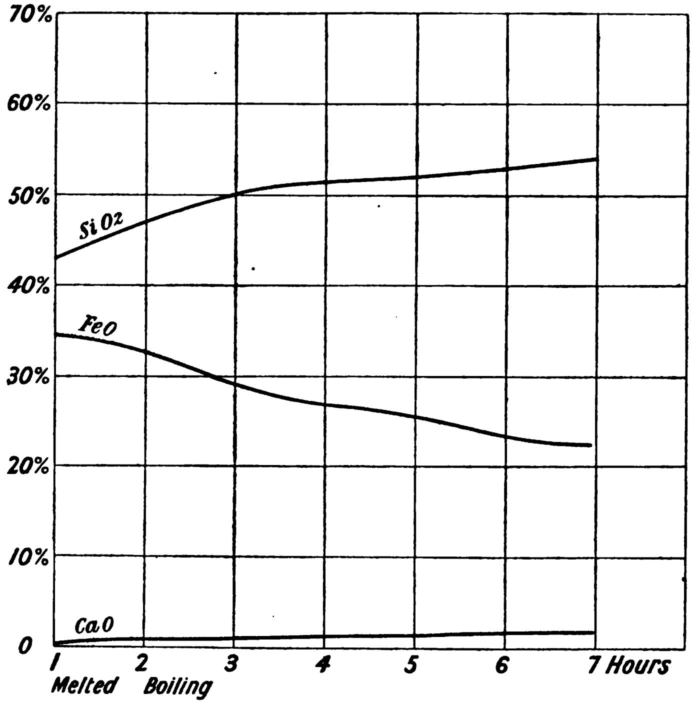
Condition.	SiO_2.	FeO.	CaO.
Melted . .	45·1	31·5	0·50
Boiling . .	50·0	29·5	0·80
1 hour after .	57·2	21·0	6·1
2 hours after .	60·1	17·5	9·5

FIG. 5.—Chart 1.

slag. They are taken from a number of heats and are typical of CaO effect.

A highly siliceous slag low in FeO may be obtained quickly after boiling. A slag of "finishing condition" is formed soon after the charge has gone to boil by correct addition of lime-

stone. If it is advantageous to work with a slag of a highly siliceous character towards the end of the boil, surely the earlier



Condition.	SiO_2.	FeO.	CaO.
Melted . .	42·9	35·0	0·56
Boiling . .	46·7	32·0	0·59
1 hour . .	50·1	29·0	0·89
2 hours . .	51·0	27·0	1·02
3 ,, . .	51·5	26·3	1·35
4 ,, . .	52·0	23·0	1·50
5 ,, . .	53·0	22·5	1·43

FIG. 6.—Chart II.

stages would be benefited by such similar conditions. The rate of fall in carbon is more regular and consistent with good results. Although the slag is apparently more mobile, it merely indicates in these circumstances a perfect state of flux and correct reaction.

The question of the effect of limestone is introduced in order to raise the point of its action upon occluded "slag" in the bath.

The nature of the acid hearth is one of silica and silicates of iron mostly. See Fig. 9 (section of bath). The slag of the process is also silicates of iron and manganese, so is the nature

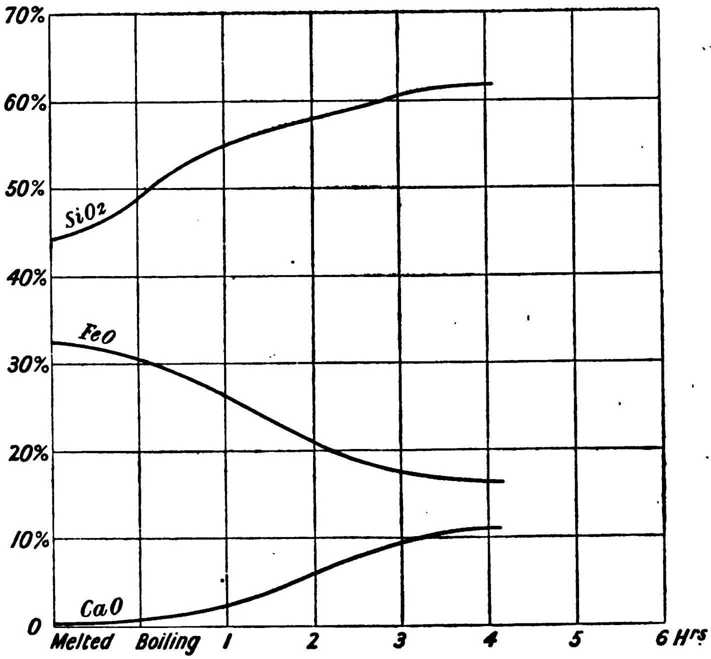


Fig. 7.—Chart III.

of any occluded particles. The hearth when new is in a highly receptive state, and absorbs a large quantity of the oxides formed during melting. After a few heats, however, this absorption ceases. The melter usually remarks upon the first few heats regarding the "boil." The reaction and appearance do seem a little perplexing, and certainly different when the hearth has satisfied itself.

Under normal conditions therefore we have in this process a bottom, and slag of a similar composition to the occluded matter. Without the addition of CaO the slag runs about

50 per cent. silica, but with correct CaO addition it may reach 62 per cent. It may be argued that a slag capable of retaining 60 per cent. SiO_2, and being in a fairly mobile condition, would more readily absorb from the bath any suspended particles of "slag" than one low in SiO_2 and comparatively high in FeO.

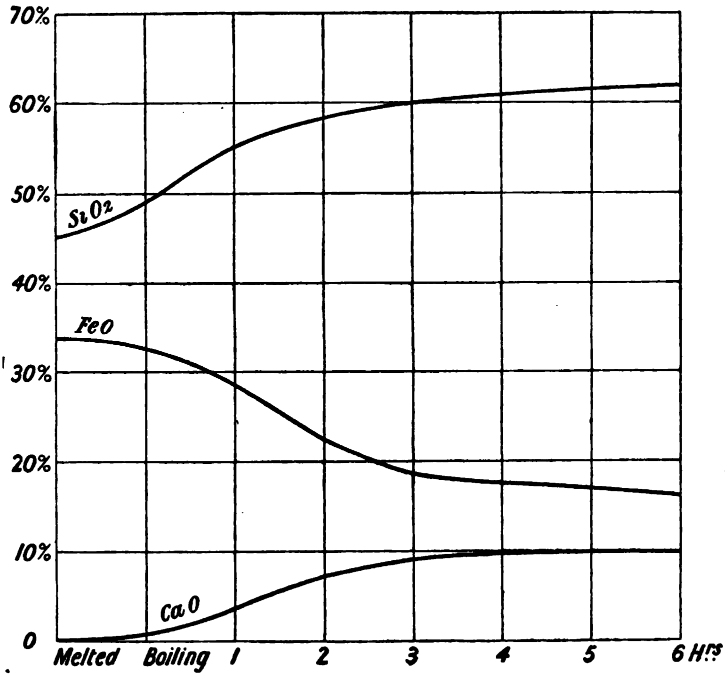


FIG. 8.—Chart IV.

Lappiness in Ingots.—Bottom-cast steel poured at too low a temperature or too slow a speed tends to cause "lappiness" or "folds" in the ingot. Ordinary carbon steels of course do not suffer much from this condition, since if the steel is so cool as to "lap" badly, the chances are much againt the ingots filling. Chrome steels and high silicon steels (the latter up to 2·50 per cent. silicon) are almost always apt to subject themselves to lapping in a more or less degree. The appearance of the ingot may give

some idea as to whether the lapping is going to be a serious defect or not, but on the whole it is a matter for further investigation. It is thought by some steelmakers that the lapped portion of the steel becomes coated with a film of oxide, which is embedded in the ingot by the flow of steel over it; also, that this forms the beginning of a flaw in the rolled bar, taking the form of a crack or split, after the bar has been subject to pickling. The author is of the opinion that any cavity or split in a rolled or forged bar has no relationship whatever with lapping in the ingot. This

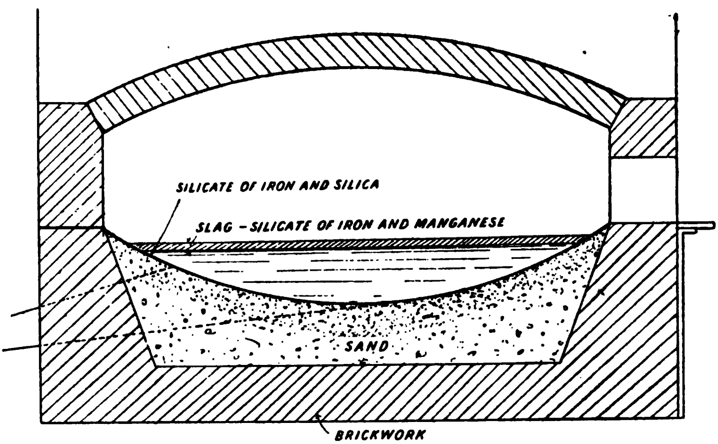


FIG. 9.—Section of Acid-lined Furnace.

opinion is based upon a number of nickel chrome and chrome ingots, carefully watched throughout their making, and on a careful comparison of the cost of chipping out of flaws (nine in each cast separately) in the finished bars. Some of the best casts appeared to be the worst as regards laps, and summing up one could not say that the lapping was as serious as would be supposed. The use of comparatively large nozzles in the ladle, and a small number of ingots per bed, lead to what the author terms spasmodic teeming, the stream from the ladle running at full force being of greater volume than is compatible with correct filling of the moulds. The teemer has then to use his

discretion and endeavour to control the stream to fill the moulds correctly. What is obtained is an ingot teemed at various speeds and in a good many places; the stream being momentarily cut off, one would expect trouble from such teeming, which may wrongly be put down to the steel having a habit of lapping. See Fig. 10.

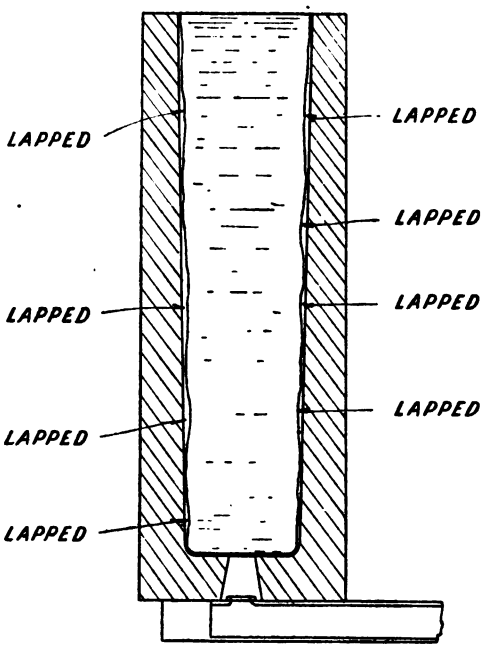


Fig. 10.—Ingot filled unevenly may cause—1. Laps. 2. Uneven solidification, uneven contraction, cracked ingots (cross sectional).

Fluxed Runner Bricks, &c.—In bottom-cast steel the flow of the metal in contact with the fireclay trumpet pipe and runner bricks causes an erosion, the product of which is carried along into the ingot. The extent to which the erosion is carried depends mainly upon the composition of the steel and the casting temperature. It is more or less common to all bottom-cast steel.

Low carbon steel attacks the fireclay material much more

readily than the higher carbon steels. Axle and low carbon forging material, which have to be machined and closely inspected, are much subject to rejections owing to the occlusions being rendered visible. Ordinary billet material, although suffering from the same evil, may escape severe notice; moreover a sandy billet may be thrown out here and there without serious loss or raising comment, the yield not being so greatly affected as where the defect shows upon a large article.

The author contends that all bottom-poured steel is subject to occluded fluxed runner bricks, and that it is present in the ingot in various positions, but principally from the skin to a depth of a few inches. The tendency for this "slag" on entering the mould is to rise to the surface and towards the sides of the ingot, the flow of the steel carrying it to its final position. Seeing that the steel in the immediate vicinity of the mould begins to solidify on contact, the fluxed runner brick has little opportunity to reach the actual face of the ingot and become merely a surface defect. Those whose duty it is to examine bars rolled from ingots having these inclusions know only too well to what depth the defect may run; unfortunately only a proportion is so near the surface as to be observed and chipped out or the material scrapped. Apart from material actually fluxed by the flow of the steel we get the "jointing" (used in the trumpet and runner brick joints) washed off in fairly large pieces, often too large to become fused. The position taken up by these pieces of "dirt" is similar to that of fluxed runner, &c. Extraneous matter such as fireclay jointing may be largely eliminated by using a suction ejector down each mould and a "trumpet" pipe immediately prior to casting.

Cracks in Ingots. Acid Open-Hearth.—There are two positions in which cracks are chiefly experienced in ingots:

1. Cross sectional.
2. Vertical, and principally at the corners of square or octagonal ingots.

Around the subject there rises the point of casting, temperature, and teeming speeds. Chart V. (Fig. 11) (casting details) is to illustrate the comparative margin of safety in casting ingots free

from cracks under varying nozzle sizes and capacity per bed.

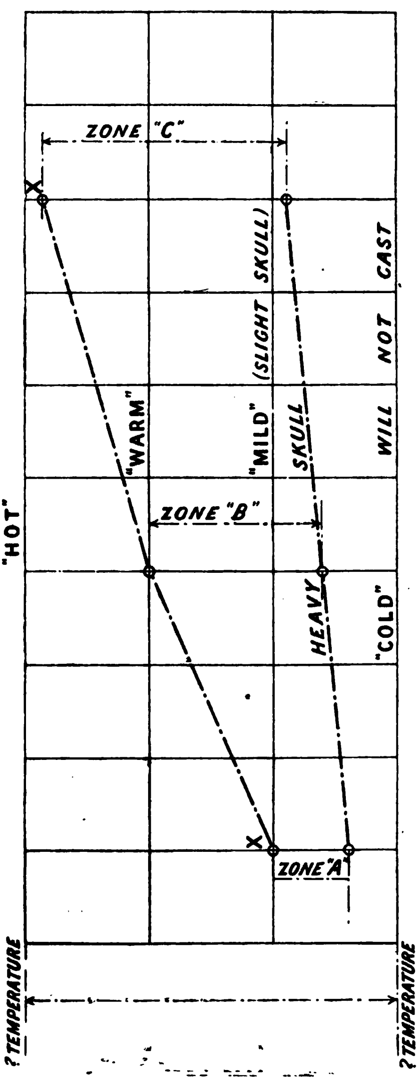


FIG. 11.—Chart V. Casting Chart (bottom-cast steel). Dealing with "casting temperature." To show comparative safety ratios to cast ingots without cracks. Zone "A."—Where the ladle running at full stream is above the capacity of the ingots on the bed, and the rate of filling rests entirely with the control of the stopper by the teemer. Zone "B."—Where the number of ingots per bed is just under the capacity of the ladle, casting at full stream. Zone "C."—Where the nozzle size and the capacity of the bed balance when casting full stream, the steel tending to freeze slightly on the surface during filling. Above the line "XX" cracked ingots prevail.

For top-poured steel, zone A may be taken for direct-poured ingots against zone C for correctly "tun dished" ingots.

The value of pyrometry as a means of controlling furnace

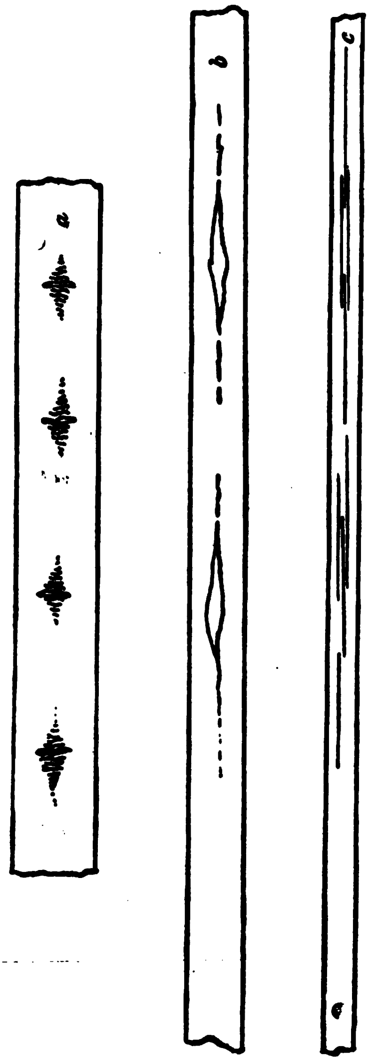


FIG. 12.—Chart VI. Rolled Ingots. Development of cracks during rolling. *a, b, c*, showing one face of ingot and the form the cracks mostly take.

or casting temperature is unfortunately very small to the steel-maker, and he has to be guided by his experience of the appear-

ance of the furnace, slag, and spoon samples. In nine cases out of ten one cannot talk of hot casts where a skull is left, yet ingots made from such steel will crack in working, and very badly if teemed comparatively quick.

In a number of the works visited by the author the actual teeming times of weight of steel per minute have been little studied, and the reason for cracked ingots has invariably been attributed to heat. The only exceptions to this view have been where speed was thoroughly considered.

Discussion upon hot and mild temperatures in the casting of steel would often lead one to suppose that the actual difference in degrees of heat was extremely great. Granted that it is an easy matter, when once the steel is being cast from the ladle, to say what the temperature is like, it is a different matter accurately to judge from the furnace condition to the fine points necessary.

The human element shows itself very prominently in the open-hearth steel trade, and some compromise has to be arrived at which will average all conditions and give the simplest way to success.

The question of size and weight of ingot and weight of steel to be cast are all factors for consideration, as also the use of and the composition of the steel.

Appended are two tables of speed of top-poured ingots and one of typical casts of bottom-poured ingots, showing relative proportions of cracked bars.

Table I.—*Teeming Speeds. Record of a Number of Various Size Top-poured Ingots Free from Cracks.*

Weight.	Section.	Time of Teeming.
15 cwt.	12 inches square	2 minutes.
25 ,,	14 ,, ,,	$2\frac{1}{2}$,,
50 ,,	20 ,, ,,	$5\frac{1}{2}$,,
60 ,,	22 ,, ,,	6 ,,
80 ,,	24 ,, octagonal	8 ,,
100 ,,	28 ,, ,,	9 ,,
12 tons	36 ,, ,,	18 ,,
20 ,,	40 ,, ,,	25 ,,

TABLE II.—*Teeming Speeds.*

40 tons capacity cast, 0·45 per cent. carbon steel. Ingots 50 cwt., 20 inches square (50 casts).

Time in Minutes.	Ingots Cracked at Mill.	Bars to Chip due to Cracks.
2	All badly	Nearly all
3	50 per cent.	40 per cent.
3½	40 ,,	30 ,,
4 [1]	10 ,,	8 ,,
5 [1]	5 ,, slightly	4 ,,
6 [1]	2 ,, very slightly	2 ,,
7 [1]	None	2 ,,

[1] Tun dished.

TABLE III.—*Teeming Speeds (Two Typical Heats).*

30-ton heats, 0·45 per cent. carbon steel. "Bottom cast." Ingots 12 inches square.

Nozzle in Ladle, 1 *inch* (5 cwt. skull).

Bed No.	No. of Ingots per Bed.	Weight per Bed.	Time. Minutes.	Bars to Chip for Cracks.
1	6	90 cwt.	4	None
2	6	90 ,,	4	,,
3	6	90 ,,	3½	,,
4	6	90 ,,	3½	,,
5	6	90 ,,	4	,,
6	4	60 ,,	2	A few
7	2	30 ,,	1½	All
		Nozzle in Ladle, ¾ *inch* (4 cwt. skull).		
1	6	90 cwt.	5	None
2	6	90 ,,	4½	,,
3	5	75 ,,	3½	,,
4	6	90 ,,	4½	,,
5	6	90 ,,	4½	,,
6	4	60 ,,	3½	,,
7	2	30 ,,	2	A few slightly
2	top-poured		1	Nearly all

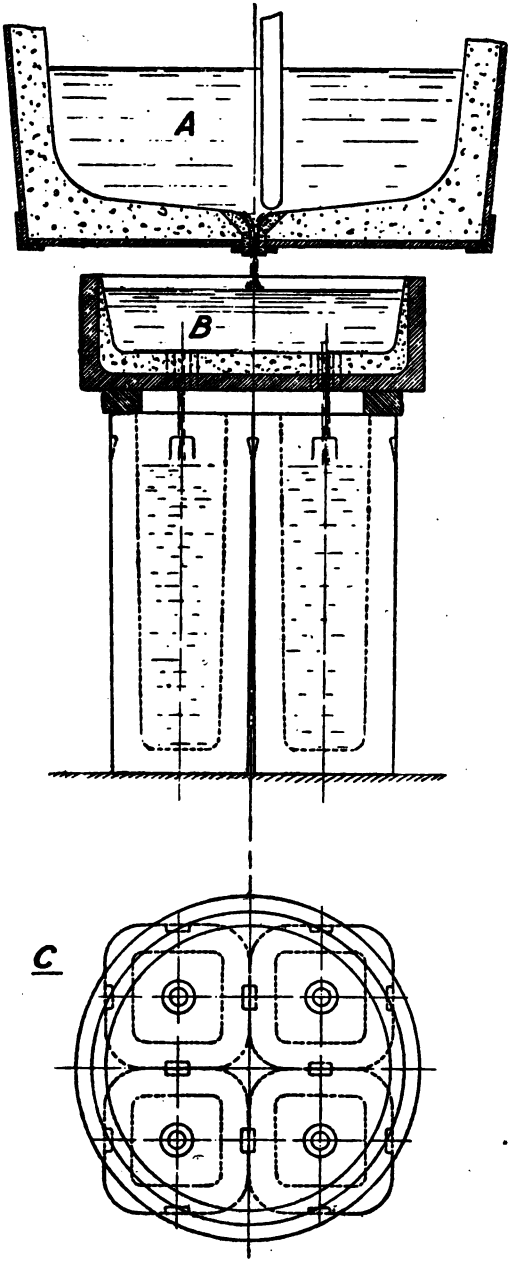


FIG. 13.—Showing four-way flat bottom circular tun-dish filling four very small moulds at a time. A. Casting Ladle. B. Tun-dish. C. Plan of above.

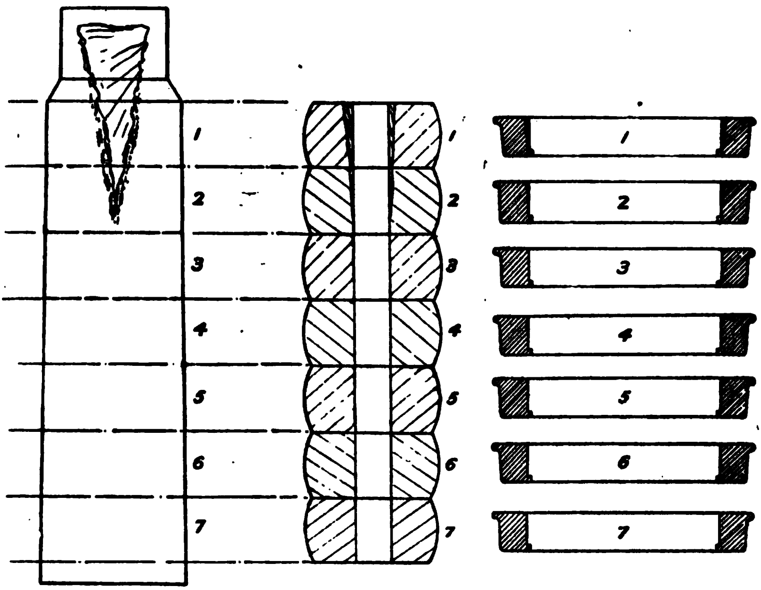


FIG. 14.—Tire Steel. Ingots narrow end up. Showing big possibility of segregated steel in the tire, and probable cause of bad "drop" test.

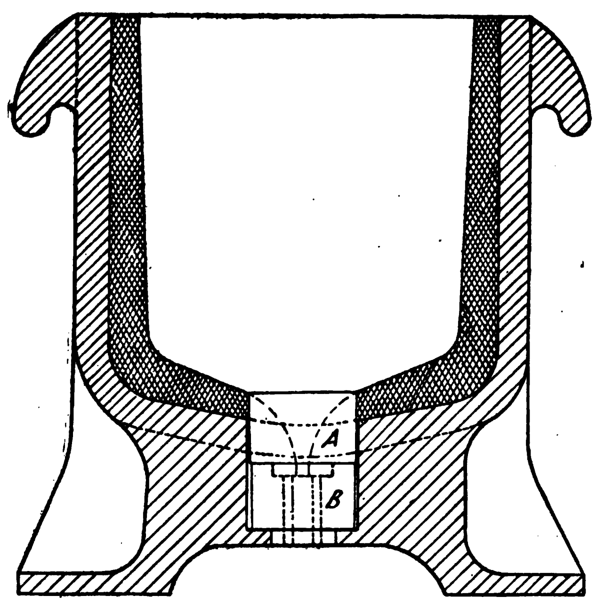


FIG. 15.—Single Tun-dish. A, B = Fireclay-magnesite nozzle (Williamson). Tun-dish goes a large number of heats, and gives a "clean" stream with minimum splash.

DISCUSSION.

Mr. J. E. Fletcher (Dudley) said Mr. Kilby's paper was reassuring to those who had to work up, in rolling-mill or forge, purchased ingots in which the defects enumerated were not rarely found to exist. His (Mr. Fletcher's) own experience confirmed the author's views, that forgings made from slowly run wide-topped ingots with hot feeder heads and top cast were freer from surface and internal flaws than those from the older type with wide base and bottom cast. The special feature in the paper to which he wished to draw attention was that relating to the slag function as influencing the elimination of included slag and oxides. The author had described his method of insuring a quiet bath well calculated to yield a more perfectly killed steel, free from the dirty condition of metal when refined by drastic ore additions towards the end of the operation.

Though the addition of lime to an acid bath was not new, the diagrams Figs. 5, 6, 7, and 8 portrayed clearly what happened when the slag passed from a normal acid condition :

$$\left(\overbrace{FeO + MnO}^{} + SiO_2\right)$$
$$\text{55 per cent.}\quad \text{45 per cent.}$$

to the special one expressed thus :

$$\left(\underbrace{FeO + MnO + CaO}_{\text{38 per cent.}} + \underset{\text{62 per cent.}}{SiO_2}\right)$$

It was interesting to compare those altering conditions by plotting the results somewhat differently (see Fig. A). As the refining progresses the slag temperature increased, each new temperature corresponded with a new equilibrium governing the composition of the slag, which equilibrium, as Juptner, Akerman, and Vogt had suggested, was undoubtedly related to the ratio $\frac{\text{acid 0 per cent.}}{\text{basic 0 per cent.}}$ That ratio, shown by line XX in Fig. A, closely followed the SiO_2 curve.

Now, as the added basic oxide lime was not reducible at the temperatures of the steel furnace, the alteration in the slag composition was brought about by the reduction of manganese and iron, the shaded areas between the falling curves AB and CD showing that action plainly. Such reduction of iron and manganese and the simultaneous change in the slag composition were of course complementary to each other, and those actions could not occur except during the elimination of carbon and silicon from the bath. The author had proved that by thus carefully adding lime, together with the requisite silica as slag at the commencement of the melting period, the carbon dropped more regularly, and from the more mobile condition obtaining in the new "limey" slag, that could be readily understood to be the case,

His contention that such slag addition early in the refining stage was advantageous, was obviously correct, the protection of the metal from oxidation during melting being thereby assured. Experiments made in melting a pig iron charge under a liquid slag in puddling furnaces had yielded similar results.

The 62 per cent. SiO_2 slag, when superheated far above its fusion point (which would be in the region of 1150° C.), became less viscous and increasingly active chemically. In such a condition it was well fitted to attack any free FeO or Fe_2O_3 with which it came into contact, rising from the bath in company with the escaping CO. As in the puddling process, the refining actions were brought about by the active oxides FeO,Fe_2O_3, carbon and silicon being eliminated from the bath thus:

$$\left.\begin{array}{lr} & 4Fe_3C + FeO,Fe_2O_3 = 4CO + 15Fe \\ \text{or} & 4C + FeO,Fe_2O_3 = 4CO + 3Fe \end{array}\right\} \quad . \quad . \quad . \quad (1)$$

$$\left.\begin{array}{lr} \text{and} & 2Fe_2Si + FeO,Fe_2O_3 = 2SiO_2 + 7Fe \\ \text{or} & 2Si + FeO,Fe_2O_3 = 2SiO_2 + 3Fe \end{array}\right\} \quad . \quad . \quad . \quad (2)$$

Such was the character of the reactions when furnace temperature and reducing atmosphere were perfect. Generally, however, some of the Fe_2O_3 (either from the ore or from furnace atmospheric oxidation of the FeO) remained in the bath and as such became persistently present, entrapped within the molten steel, possibly in the form of a silicate or iron, as in the case of puddled iron. In both the acid open-hearth and puddling processes, especially when cold or slow melted, the oxide Fe_2O_3 was found in the slag, the content diminishing towards the end of the boiling stage, but increasing again if the finishing stage of refining were completed in an oxidising atmosphere at too high a temperature.

It was noteworthy that the 62 per cent. SiO_2 slag aimed at corresponded with the composition $RO,2SiO_2$, where $RO = CaO + MnO + FeO$. The normal acid slag of about 45 per cent. SiO_2 was of the type RO,SiO_2, the temperature of formation (according to H. O. Hofman) being 1120° C. The same authority showed the 62 per cent SiO slag to be the most fusible of the series, its temperature of formation being given as about 1100° C., an interesting corollary to the subject at issue. The slag indeed might prove to be the eutectic of the RO,SiO_2 series, and if so it explained the sensitiveness of its character and the ease with which it released MnO and FeO to the bath whilst taking up the lime to attain its equilibrium. He (Mr. Fletcher) had added Fig. B as illustrating the above interesting phenomena. The curve showed the heats of formation of the slags ranging from 30 per cent. SiO_2 to 70 per cent. SiO_2.

The inclusions of slag were a far more common trouble than steel-makers generally cared to admit, and Mr. Kilby deserved high praise for indicating means both inside and outside the melting furnace whereby the difficulties could be largely overcome. The human factor, especially on night turns, was an extremely awkward one to

control, and the great liability to slipshod fitting of runner bricks and runner connections, stamped the bottom-run ingot as a danger. In the matter of spalled tubes and eroded fireclay particles (to say nothing of the carrying over into the mould of slag from the ladle in the last batch of ingots cast from an almost empty ladle, where the slag flowed over the lip of the vortex of the final hollow stream), the bottom cast ingot had much to answer for.

The "woody-fibred" test fracture, breaking with ominous silence, always bore witness to the presence of slag. The engineer should, however, be able to look forward with greater feelings of security to the days of top-cast feeder-headed ingots, slowly run through the tun-dish. The use of the latter would surely eliminate many of the difficulties which arose from the violent bottom splash, resulting from the unbroken fall of a stout stream of steel impelled at high velocity under the heavy pressure head in the large ladles of modern melting shop practice.

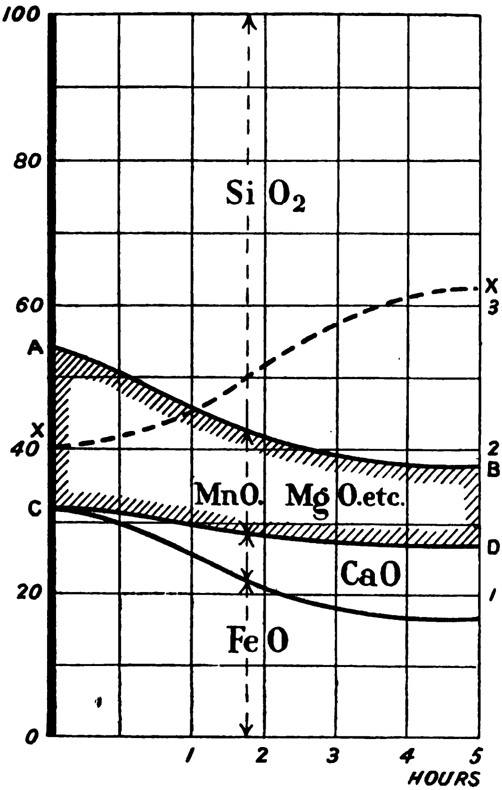


FIG. A.

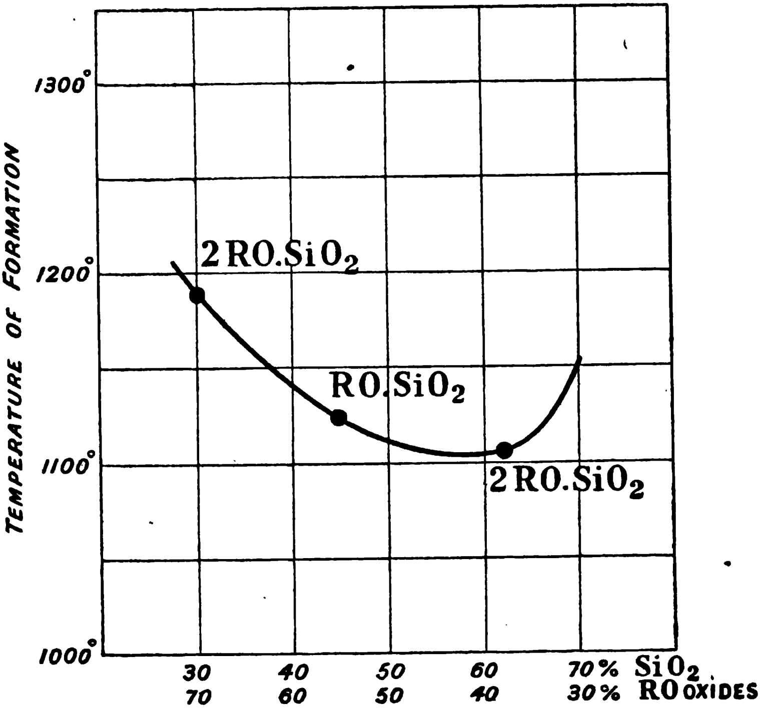


FIG. B.

Dr. W. H. HATFIELD (Sheffield) thought the Institute was indebted to the author for his able paper, which was a valuable addition to the literature of sound steel and ingot defects. Any practical steel-maker would entirely agree with the bulk of what the author had written. It seemed, however, to have been forgotten that Professor McWilliam and he (Dr. Hatfield) in 1902 and 1904 published two papers which contained the result of something like four or five years' work in connection with the action of the slag upon the steel, and that during their investigations they studied not only the composition of slag but of the steel, and brought out very clearly a fact which had been since confirmed on numerous occasions—that if it were assumed the slag in the acid Siemens consisted essentially of the silicates of iron, as the carbon reduced the iron and sent up the silicon content in the slag, a position of equilibrium was arrived at. Then, with further reduction of the iron contents, the silica was actually sent up to such a percentage in the slag that it was split up and the silicon went back into the steel. The author discussed the addition of limestone. The diagrams given in the paper would be much more valuable if he could, either in that

particular instance or subsequent examples, give the influence of the addition of the fairly large quantities of lime, which he recommended, upon the actual chemical reactions taking place between the slag and the steel. For instance, if much limestone were added to the slag it must of necessity shift the percentage point at which the silicon would go back into the steel. Another matter to which he (Dr. Hatfield) wished to draw attention was the author's statement that "The presence in ordinary carbon steels of this finely divided or emulsified solution of slag is just as little desired as in the case of special steels, although not so liable to influence ordinary physical tests called for in these steels." He would suggest that the disadvantage of the slag inclusions was equally great in both carbon steels and alloy steels, and he would like to know the data upon which the author made that discrimination. The author gave an interesting set of figures showing the effect of the various speeds of teeming upon cracking. It would be additionally useful to every one if he could make sketches showing the configuration of the ingots and the nature of the defects, and the direction of the cracks in each case. If any variation occurred in their relationship to the shape of the ingot, the variation should be indicated.

Mr. E. H. Saniter (Rotherham) said the new type of nozzle shown by the author was a very interesting one and more should be heard of it. He was rather surprised, after the author's strictures upon that method of casting, to notice on p. 89 an ingot cast with the big end down. With regard to what Mr. Fletcher had said about buyers of ingots, he would not like it to go forth that the only defects which might turn up in an ingot, before it was finished into a forging, were those that were met with in casting. It was very easy, after an ingot had been allowed to cool, for the forge people to injure it by cracking or burning during heating unless great care was used. He would not like it to be thought that if there were a defect in a forging it must have been necessarily a defect caused in the casting of the ingot.

Mr. C. H. Ridsdale (Middlesbrough) said the question of slag related to acid open-hearth, but the analogy would hold good in other directions, and he had abundant corroboration from the basic process that the moment lime was added to a charge the effect was to throw out oxide of manganese and oxide of iron from the slag into the metal, so that the effect, more particularly as regarded manganese, was exactly equivalent to adding so much manganese to the metal. There was no doubt that would also occur in the case of acid open-hearth steel to a certain extent. He was more than ever impressed by that little point as to the difficulty of applying pyrometry in practice. It was well known that a great advance had been made in pyrometers, and it was a desirable thing to get everything cut and dried within narrow limits, but still there seemed insuperable difficulties in applying

pyrometry in practice, and, as the author had said, when the cast was in the ladle it had to be poured whether it were the right temperature or the wrong temperature. The difficulty was, of course, to find a way to use a pyrometer to help to control the temperature at which the cast was taken. With regard to the question of the "best casting temperature," he supposed that for any given composition of steel, say a 0·20 carbon steel, there would be, from the steel point of view, a best temperature, but that was not necessarily the "best" from the shop conditions point of view. As the author had pointed out, the men were all on tonnage and had to get the maximum weight of ingots out in a shift, and the particular temperature which was ideal for steel of the composition that was being cast might not fit in with the shop conditions. There were so many factors—the size of ingots, the size of the nozzle, and so on—which really amounted to saying that the personal element of the teemers had to be taken into account.

Mr. E. Adamson (Sheffield) said the composition of slags was an indication of temperatures, and the temperature of slag was not necessarily that of the metal; until there was some correlation between the composition of the slags and temperatures of the slag and metal there could be no accurate data. He had made investigations in connection with electric steel, &c., and was of opinion that temperature had more to do not only with the quality but with the defects of the resultant steel than almost anything else. Therefore, to his mind, the slags were simply indications, and until pyrometers could be obtained to measure the temperatures of slags and of molten metal, both in the furnace and in the ladle, he did not think any definite conclusion could be reached. Temperatures during the manufacture of steel played a more prominent part than had been generally believed, and, in his opinion, further investigation in that direction would elucidate many of the problems involved.

That view was confirmed by the author's opinion expressed in the paper, where he spoke of hot casts. It was quite possible to have skulls from hot casts under the same law that hot water was liable to freeze sooner than cold, and as he (Mr. Adamson) had shown on several occasions, the higher the temperature of pouring cast iron, the deeper the chill. Therefore, the higher the temperature of steel and the colder the ingot mould, the more liability was there of the molten metal, in contact with the mould, chilling. It was quite conceivable that an ingot mould was not at an even temperature over the whole inside surface at the time of casting, which suggested perhaps a partial explanation of the cause of the variations shown in Fig. 10. It was also possible that that might partially account for liability to surface cracks.

In all cases of varying temperature during the whole process of making steel, the author was correct in saying that the human element entered, and the superiority of one melter over another was constantly

in evidence. Particularly was that so in the case of a "wild" heat, which a good melter should be able to modify whilst the metal was in the furnace, and work it down to a suitable casting or "finishing condition"—referred to by the author on p. 77—before the furnace was tapped, thus saving what might otherwise have been a lost cast.

Mr. W. J. FOSTER (Darlaston) said he was only one of those poor blast-furnace managers who were not supposed to know anything about steel, but he had been very interested in the paper, particularly in the author's remarks with reference to the temperature of casting, and he thought he was to be congratulated on making a research into the matter so carefully as he had done.

With reference to the slag question and the fluxing of the material, he was rather inclined to think that too much stress was being laid upon that point in the discussion, to solve the problem as to cracks that might arise in ingots. For the last two and a half years he had been experimenting extensively in trying to obtain a cast iron shell with a low total carbon and had been more or less successful, and he noticed in the experiments that if he wished to get his casting with a low total carbon very solid and free from cracks he obtained the best results by disregarding the exact speed of pouring and a definite temperature of the metal and by getting large chills—*i.e.* he made the chill very heavy in proportion to the amount of metal dealt with. The result was that by cooling the metal down quickly he found that he obtained very solid castings, and it appeared to him that in the question of casting steel ingots, if the ingot moulds were made heavier in proportion to the steel dealt with, very much sounder castings would be obtained. The question to his mind was more a physical than a chemical one.

With reference to the question of pipe the cause was simply a question of liquid contraction, and could be avoided, assuming the metal could be chilled from the liquid to the solid state sufficiently rapidly. That was also a physical proposition. He made those definitions for the reason that he felt that the fundamental principles of the noble science of chemistry were often abused, and particularly was that so during the numerous discussions that took place from time to time on the metallurgy of steel.

Mr. T. M. SERVICE (Glasgow) said the author did not appear to attach much importance to pyrometers as a means of controlling the temperature in the melting furnace, as evidenced by the remark that "the value of pyrometry as a means of controlling furnace or casting temperatures is unfortunately very small to the steel-maker, and he has to be guided by his experience of the appearance of the furnace, slag, and spoon samples." In works where high-class alloy steels were manufactured it was customary to control, by pyrometers, the heating of the steel for rolling or forging and other later treatments;

it often happened that after very careful heat treatment and material having successfully passed tests, such material was rejected through slag inclusions being detected during machining. In a paper read before the West of Scotland Iron and Steel Institute, McCance showed that those slag inclusions were principally composed of manganese silicates, which were formed by the action of the ferro-manganese on the slag emulsified or held in suspension in the steel; from that it appeared that the melting furnace was the proper place to try and eliminate non-metallic impurities. A record was taken some time ago of the casting temperatures of nickel-chromium steels, the results being as under:

Temperature	Over 1460° C.	1455°–1440° C.	1435° C. and under.
Number of forgings made	164	151	49
Number rejected	22	38	16
Per cent.	13·4	25·2	32·7

From the figures given, and also from the fact that so much care was expended in the after-treatment of steel, did it not appear evident that the control of melting furnaces by the pyrometer should be undertaken as against the present experience and eye method? Had the heat treatment of steel been carried out on the same basis very little if any improvement would have taken place.

The author's remarks as to the amount of silicon in the charge were important, but he (Mr. Service) would like to know how the addition of slag to the charge added to the silicon content of the charge. The silicon in the charge was already combined, and as far as he could see it could in no way be either oxidised or reduced by the action of the gas or the melting charge. Would it not be better to add ferro-silicon along with the charge, as by this means there would be a definite percentage of silicon to oxidise?

Dr. C. H. Desch (Glasgow) said that one part of the very suggestive paper pointed to the necessity of a very thorough scientific investigation of the open-hearth slags. That seemed to be one of the most urgent pieces of scientific work needing to be done just now. Reference had been made to the chemical composition of the slag. As Dr. Hatfield's work had shown, there was a chemical equilibrium in such cases. In a highly acid slag there might be silicon passing into the bath; in a highly basic slag there were changes in the other direction. The introduction of any new base, such as lime, altered the equilibrium in a way that at present was little understood. There were other properties of slags which were likewise of great importance. The rate at which a slag could eliminate itself from a bath depended not on the chemical composition, or only indirectly on that, but directly on the physical properties, the viscosity, surface tension, and specific gravity. Adding lime to a slag in such a way as to replace ferrous oxide had the effect of reducing the specific gravity, and to that extent to favour elimination, but the effect on surface tension was much less

known. All those questions needed investigating very thoroughly. The problem of the elimination of slag was really a colloidal one. There was a colloidal suspension of silicate and oxide particles, as well as of manganese sulphide in the steel. Therefore a physical investigation was needed as well as a chemical one. The author seemed to suggest that slag inclusions, when small, were not of much importance in ordinary steel. From examinations made of a very large number of fractures in small machine parts he had come to the conclusion that slag inclusions were always bad, however minute they might be, and in small machine parts subject to great alternating stresses, when a fracture did occur it might be traced, in a very large number of cases, to the presence of slag particles. The ideal steel would be one that contained no slag particles whatever.

Dr. F. Rogers (Sheffield) claimed that the state of knowledge of the reactions in the furnace, especially the acid open-hearth, was by no means so dark as the remarks of Dr. Desch and others might suggest; he would, however, deal incidentally in his own remarks with those points. A number of terms were used very vaguely by speakers or in the paper, for example, temperature; but a much greater example was the "condition" of the bath or slag. That term was often used to cloak ignorance, but ideas ought to be as definite as possible on the point. The condition of the bath consisted of four principal factors: first, the temperature; second, the percentage of oxygen present—and that was essentially different in the slag and in the metal; third, the composition of the metal and of the slag at the moment; and fourth, the composition of the slag as apart from what was produced definitely by the first three conditions mentioned, that was, the effects of the addition of any old slag, or matter which came from additions to the charge, or accidentally, which might include scale, sand, and so on. With regard to the temperature, a good deal could be done with the aid of pyrometers, but he had not found any of them to be sufficient, and his own efforts in the direction of inventing a pyrometer to overcome the limitations involved were as yet not completely successful. But he quite well knew the temperature of the bath, vision being also supplemented in many little practical ways, so that the control and investigation of the process presented no difficulty in that respect. The temperature could not, however, be expressed to his satisfaction in standard degrees. Also he held that there was no vast difference in temperature in the acid open-hearth between slag and metal in proper working after clear melting; and when investigation showed that this mattered it was easy to assist convection and ebullition effects by using a bar to stir the bath. He was rather opposed, as a general thing, to utilising old slag with the charge; but in certain cases it might be best, depending upon the raw materials available for the charge. He was opposed, again only as a general principle, to the use of lime early in the charge. His views on the action of lime might help to confirm this. Suppose

that lime was not required to keep the slag thin on account of matter which had come in with the charge, then after having boiled down the charge the lime could be added very late on, even some time after the final ore addition. A boil soón commenced, and the principal factors in the action which occurred were as represented in the two formulæ, I. and II. Before adding lime the slag contained so much

$$\frac{\text{Slag}: \mathrm{FeO} - \mathrm{SiO_2}}{\text{Metal}: \mathrm{C} - \mathrm{FeO}} \qquad\qquad \frac{\text{Slag}: \left.\begin{matrix}\mathrm{CaO}\\ \mathrm{FeO}\end{matrix}\right\} - \mathrm{SiO_2}}{\text{Metal}: \mathrm{C} - \mathrm{FeO}}$$

I.—Before adding Lime. II.—After adding Lime.

iron oxide and silica; the metal contained a very little, but very important, amount of iron oxide, and some carbon. After adding lime, the silica of the slag had to share itself between the iron oxide and lime—or, in other words, so far as the particular equilibrium was concerned, some iron oxide was now freed by substitution by lime, and this iron oxide now at once began to react with the carbon in the metal. So also did some of the small amount of iron oxide in the metal, and the net result was a decrease of the total amount of iron oxide in the whole system. This reduction of iron oxide, being shared in by the metal, was obviously of the greatest value. Speaking of dead melting, iron oxide could also be minimised in the whole system by an increase of temperature. That sounded rather paradoxical, because the oxidation by the furnace atmosphere would usually be greater if the temperature were forced up. The slag was readily oxidised by the flame, and there was a limit which could not usefully be exceeded, where one action would overwhelm the other. The inclusions in ingots of the weight dealt with in the paper he had in the majority of instances traced to fluxed bricks, and runner bricks were greater sinners than stoppers and nozzles. The runner brick was porous and held a cushion of hot air in close contact with the rushing stream of metal which was ready to oxidise, and the metal oxides were very ready to unite with the silica of the clay—all the conditions therefore favoured the fluxing of the bricks. He maintained that ingots with the large end up were the ingots of the future for the great majority of purposes, principally because that form had the advantage in regard to piping and segregation. Various details, some of which had been mentioned by the author, favoured that form of ingot, and in particular it was on the whole simpler to handle and lent itself most favourably to top casting.

Mr. Kilby had devoted a special paragraph to "fluxed firebrick" as one kind of inclusion met with in steel—referring, of course, to the mixed manganese and iron silicates with high percentages of alumina, and the origin of that material had been to him (Dr. McCance) a matter of considerable doubt, but some experiments which he had recently made threw some light on that question, and left no doubt that manganese silicate exerted a strong solvent action on the alumina in firebrick. In one case the amount of alumina had been increased from 2·1 per cent. to 11·5 per cent. when an impure manganese silicate was melted in a fireclay pot. It was possible that slag exerted a preferential solvent action on the clay substance in the firebrick.

Although he had differed from Mr. Kilby on some points he felt very greatly indebted to him for his most stimulating paper, and he was sure that Mr. Kilby would agree that a conflict of views was even desirable, because it defined the issues more clearly, and issues could only be decided by the results of constructive experiments.

Mr. J. H. Whiteley (South Durham Steel & Iron Co.) wrote that the author had touched upon many interesting points, among which were to be included the effect of lime additions in the acid process; in that connection the following remarks might perhaps be of some use.

The analysis of an average acid slag showed it to contain about 54 per cent. of silica and, as bisilicates of iron or manganese contained only 44 per cent. of silica, it was evident that, when the slag was molten, either bisilicates and trisilicates were both present, or else the bisilicate contained the excess of silica in solution. There was no doubt, however, that at a given temperature the viscosity of the slag depended to a large degree upon the percentage of silica present. Thin slags might contain only 45 per cent. of silica or less, whereas the amount in the thickest slags could exceed 60 per cent. Now the maintenance of a thin slag during the process might lead to serious difficulties, as such slags were liable to attack and erode the banks and hearth; on the other hand, if the slag were kept too thick, the oxidation of the carbon was greatly retarded, and where output was the main consideration, it was essential to keep the slag in a medium or "open" condition. If a rapid method of estimating the silica in the slag samples could be found it would be useful as an aid in the process; as, however, that was not possible at present, the smelter, in regulating the working of the charge, was forced to rely upon the viscosity of the slag to guide him in making the ore additions. The viscosity was judged chiefly by the way in which the gas bubbles formed on the slag surface, and an experienced smelter was very proficient in detecting the variations.

The addition of a base such as iron oxide "thinned" the slag or lowered the viscosity by reducing the percentage of silica, and as the oxide was gradually removed by the action of the metalloids in the bath, the slag thickened again. The addition of lime had a similar effect, but in that case, as the lime was not afterwards removed, the

"thinning" effect was permanent. Thus, under equal conditions, a slag containing lime required a lower iron content to give it the same viscosity as another similar slag not containing lime, and as the maintenance of a certain viscosity was essential, it was clear that the addition of lime during the process must automatically lower the iron content of the finishing slag, with the result that a higher yield was obtained.

Lime additions in any quantity must of necessity be made in the early stages, and unfortunately they caused the period of the "boil" to be prolonged, owing to the fact that, in keeping the correct viscosity, the active mass of iron oxide in the slag must be proportionately reduced, and the oxidation of the carbon was thereby retarded. For that reason, in making mild steel, it did not seem possible, without seriously affecting the output, to reduce the amount of iron in the finishing slags more than about 5 per cent. (say, from 25 per cent. to 20 per cent.) by lime additions at an earlier stage. In making high carbon steels, however, the use of lime was undoubtedly beneficial, as it prevented the too rapid elimination of the carbon in the bath and so enabled the required percentage to be obtained with more certainty; also, the iron content of the finishing slag could be reduced to 15 per cent. or even less.

Mr. S. W. Williamson (Glasgow) wrote that the paper dealt with the practical side of three most important items in melting shop practice, namely, shape of mould, steel furnace conditions, and method of casting ingots. Undoubtedly, as Mr. Kilby said, the mould with wide end up would bring the pipe to the top of the ingot, though without some kind of feeder-head the advantage could hardly be very marked. It would have been interesting if some opinion had been given as to the amount of taper most suitable for different types of mould. He imagined that, to a certain extent, it might with advantage vary inversely according to the cross section of the mould.

A very interesting subject for discussion was referred to in speaking of the "value of pyrometry as a means of controlling furnace or casting temperature." The results which could be obtained by pyrometric control in the heat treatment of steel naturally suggested the possibility of controlling and standardising the methods of making steel in the open-hearth furnace. In the heat treatment of steel the temperature required was not comparatively high, and could be measured with pyrometers which were accurate to a fraction of a degree. The open-hearth furnace, unfortunately, did not lend itself so readily to a system of pyrometric control. The very high temperatures to be recorded, the impossibility of fixing a thermocouple in the bath, and the eccentricities of the different types of radiation pyrometers, left only the optical pyrometer of the Holborn-Kurlbaum type for any serious work. When using that class of pyrometer, the only temperatures which could be recorded were those of the slag and furnace linings.

If any definite relation could be established between those records and the temperature of the metal, either during the boil or after tapping, then it might be possible to establish some system of control by which the charge could be worked. In practice it was found that even when making the same class of steel in the same furnace, the temperature records taken during the boiling down of the charge did not give a reliable indication of the temperature at which the metal would be tapped. When comparing records of the making of different classes of steel, the irregularity was more marked.

Assuming for a moment the accuracy of the pyrometer, there were several facts sufficient to account for the difficulty of establishing a relation between the temperature of the surface slag and of the metal below it. The quantity of slag and the amount of movement in the bath varied in different classes of steel. The rate at which heat was transmitted to the steel below was affected by both those factors. There was also a variation in the composition of different slags, and the assumption that the emissivity of a slag varied with its composition might help to explain certain otherwise inexplicable records.

In many cases a record of high temperature during the working down of a charge was accompanied by a high tapping temperature, and *vice versâ*. Still, the discrepancies similar to that shown below were too numerous to be regarded as exceptions.

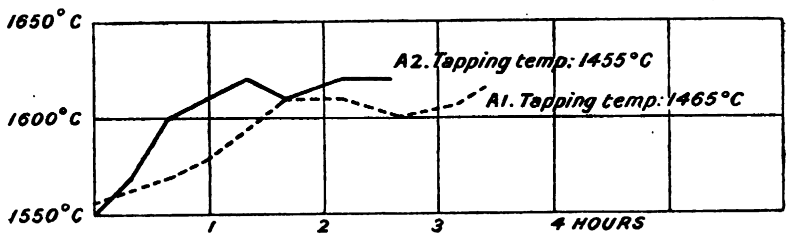


Fig. D.

The above diagram, Fig. D, represented the record of the boiling and tapping temperatures of two successive charges from the same furnace. The figures given were merely observed temperatures and needed correction. The charge A 2 gave readings during the boil, which indicated that the steel would tap at a higher temperature than in the preceding charge, A 1. When the furnace was tapped the temperature of the metal as it ran into the ladle was recorded as being 10° C. lower.

Le Chatelier[1] gave an instance of a variation of 90° C. in the temperature of a charge of steel as it ran from the furnace into the

[1] Burgess and Le Chatelier, "Measurement of High Temperatures," p. 306.

ladle. Such a difference in temperature appeared exceptional, though undoubtedly there were variations.

When the steel was being poured from the ladle into the mould a good opportunity occurred for measuring its temperature, and accurate records would very materially help to determine the cause of many "steel ingot defects."

Burgess,[1] with efficient means of calibrating his pyrometer, claimed a precision of 5° C. at 1500° C. Unfortunately, in his (Mr. Williamson's) experience of steelworks practice, such a degree of accuracy had not yet been obtained.

Mr. Kilby gave some interesting records at the end of his paper, showing the connection between time taken to fill the mould and surface cracks. It must be recognised, especially when dealing with large ingots, that such figures lost their value unless the rate of teeming was constant, or varied with the cross sectional area of the mould.

Mr. Kilby quoted a 40-inch octagon ingot of 20 tons weight which was cast in twenty-five minutes, and was free from cracks. If, when casting a similar ingot, the top part of the mould was filled more slowly than the first part in order to occupy the twenty-five minutes prescribed, it was possible that the ingot would show up surface cracks in forging. The total time gave some rough indication of the rate of teeming, but it should be accompanied by the knowledge that no section of the ingot had been cast at more than a certain speed.

Usually, transverse cracks developed in the bottom half of the ingot, but he had seen an ingot which was free from cracks in the bottom half, whilst the top half was very badly cracked. That condition was produced by extreme variation in the rate of teeming.

When casting through a tun-dish, or full bore through a magnesite nozzle, the rate of teeming was regular. When bottom-casting or teeming direct through a fireclay nozzle, the rate might vary owing to the opening out of the nozzle and consequent necessity of checking the stream.

The ideal nozzle pot had not yet appeared on the market. It had been described as one which opened out to such an extent that the flow of steel gradually increased, so that the metal rose in the mould at a constant rate. But such a nozzle could hardly be expected to allow for differences in taper of mould and variations in the shape of casting ladles.

The rate of teeming at the beginning and the end of a cast could be controlled by using a short fireclay nozzle pot fitted on to a small magnesite plug. The aperture in the fireclay pot was smaller than that in the plug, and in the first instance checked the flow of the metal. It opened out during teeming until finally the flow was determined by the size of the larger aperture in the magnesite plug, which remained practically constant.

[1] *Bulletin of the American Institute of Mining Engineers*, February 1917.

Owing to the fact that the heat conductivity of magnesite was about double that of firebrick, the smaller the depth of magnesite through which the steel had to pass, the less was the chance of the aperture closing up.

Mr. Kilby's reply to the discussion on his paper was unfortunately received too late for inclusion here, and will be found printed on p. 277 at the end of the other papers. [Ed.]

THE PENETRATION OF THE HARDENING EFFECT IN CHROMIUM AND COPPER STEELS.

By L. GRENET (Firminy).

The minimum rate of cooling required to render the influence of quenching efficacious varies to an enormous extent, according to the quality of the steels concerned. The rate of cooling necessary to secure the hardening of special steels is lower than that necessary to secure the hardening of ordinary carbon steels. The penetrative influence of heat treatment is, therefore, more efficacious in the case of special steels than in carbon steels, and this, as is well known, constitutes one of the chief characteristics of the special steels.

The difference between the influence of the heat treatment at the surface and in the centre of steel pieces, which is very considerable in the case of carbon steels but small in steels in which the hardening effect has penetrated deeply, justifies the stipulation which, for some time past, has been introduced into specifications to the effect that after hardening, but before the removal of the pieces for testing, the ends of certain pieces, such as gun parts, should be cropped.

As a further consequence of the ease with which the special steels can be tempered, it is possible to harden certain of them by mild quenching operations such as oil and air tempering, which occasion little deformation or cracking.

The copper steels have already been investigated, notably by Brustlein in France and by Stead in England. The present author has devoted himself more especially to ascertaining the influence of copper on the depth of the hardening effect, particularly in the presence of chromium.

His experiments have been made on crucible steels from Firminy. The more interesting results have been summarised in Tables I., II., and III. The following facts have been observed in this connection.

1. When, apparently, the percentage of nickel is below 5 per cent., steels containing above 4 per cent. of copper forge

badly. Confining the observations to forgeable steels it has been observed that copper, by itself, while slightly increasing the depth of penetration of the hardening effect, does not increase it sufficiently to confer on steels the property of air tempering, even when small parts, such as 10 millimetre square bars, are concerned.

It is to be remarked that if the amount of nickel that could be introduced into the steel be limited to 4 per cent. the same conclusions would be reached.

2. In the presence of chromium the copper increases, fairly noticeably, the depth of the penetration of the hardening effect to the extent of rendering the employment of chromium-copper steels a matter of practical interest. (See Table II.)

It has only been upon steels containing both chromium and copper that the more extended experiments, of which an account is about to be given, have been made.

3. None of the chromium-copper steels prepared by the author possess the property of undergoing transformation (the γ to α transformation) at low temperatures, nor, therefore, that of hardening when the cooling is exceedingly slow, whereas chromium-nickel steels rather high in nickel (4 per cent. of nickel and 1·60 per cent. of chromium) possess this property. (See Tables II. and III., steels Nos. 2, 4, and 7.)

The addition of 4 per cent. of copper to a steel (No. 10) containing 2·52 per cent. of nickel and 1·59 per cent. of chromium does not likewise communicate to it the property of hardening on very slow cooling during annealing. (Table III.)

4. The addition of nickel to steels containing chromium and copper allows of the depth of the penetrative influence of quenching being increased, but only to the detriment of the property of softening by annealing. Having due regard to the size of the pieces and the use to which they are to be put, there is an advantage to be derived from the introduction of a more or less high proportion of nickel into steel.

5. The simultaneous addition of copper, nickel, and chromium to a steel permits of the easy preparation of steels which possess a tendency to deep penetration of the hardening effect sufficiently marked to render the air-hardening of large enough pieces (for example, gearings) efficacious, without such steels losing the property of becoming softened by the orthodox

annealing processes employed in the case of ordinary carbon steel. (Table III., steels Nos. 8, 9, and 10.)

These two properties, (*a*) depth of penetration of hardening effect, and (*b*) facility for softening on annealing, can be obtained amongst steels the composition of which may vary within fairly wide limits.

6. According to the tests carried out by the author the chromium-copper and chromium-nickel-copper steels possess, after hardening and tempering, practically the same mechanical properties (tensile and impact) as chromium-nickel steels having approximately the same carbon percentage (Table IV.). It should, however, be pointed out that the chromium-copper steels assume, on quenching at somewhat high temperatures, a rather coarser grain on fracture than that exhibited by nickel-chromium steels; there is therefore more danger of their becoming burned.

Summary.

Copper increases the depth of the hardening effect in steels.

The influence of copper in the presence of chromium is marked. One per cent. of copper suffices to confer on steels containing 1·6 per cent. of chromium an interesting degree of capacity for sustaining the hardening effect in point of depth.

The action of the copper is more limited than that of nickel. All the chromium copper steels prepared by the author, containing less than 3 per cent. of nickel, soften on annealing at high temperatures, and consequently do not harden on quenching when the rate of cooling is very slow.

The simultaneous employment of copper, nickel, and chromium allows of semi-hard steels being prepared which can be hardened by air-cooling on largish pieces and yet softened by the ordinary annealing methods used for carbon steels. The limits of chemical composition within which such steels should fall are wide enough to render their manufacture easy.

The chief influence of copper, like that, indeed, of other special elements, is to increase the depth of the penetrative influence of the quenching, and consequently the efficacy of heat treatment in the interior of the pieces subjected thereto.

Apart from this influence on the depth of penetrative influence

of quenching the author has failed to detect any other useful effect of copper on the properties of steel.

NOTE ON THE HARDENING OF STEELS CONTAINING HIGH PERCENTAGES OF CHROMIUM.

The special steels most commonly employed generally contain more nickel than chromium, because the somewhat violent action of chromium, which is liable to lead to cracks while quenching, is dreaded. The author conceives it useful to recall a few statements he made on a former occasion in this connection.[1]

The rate of cooling required to lower the transformation temperature in the neighbourhood of ordinary temperatures, that is to say, in order to produce hardening, varies within enormous limits. It is very difficult to ensure uniform cooling during quenching, even when all the factors acting on the rate of cooling are rigorously defined. It is similarly very difficult, when metals which require a rapid rate of cooling are treated, to ensure a uniform degree of hardening.

If, on the contrary, metals which undergo energetic hardening on air-cooling are employed, it is obvious that when they are cooled in a liquid in which the cooling effect is more rapid the hardening will still be energetic and uniform, if the conditions of the cooling vary.

Steels containing at least 1·4 per cent. of chromium and a little copper or nickel are, in these circumstances, of a kind that can be quenched in a liquid between the temperature of 120° and 350° (real colza oil does well) without the energy of the cooling varying much, and in these circumstances there is not much fear of cracks developing.

Generally speaking pieces of medium thickness (30 millimetres or less) are susceptible of being so treated, whereas the steel from which these pieces are made will air-harden if in the form of small bars. Such metals soften very well on ordinary annealing and after annealing are easy to machine. Naturally if it be desired that the hardening effect should penetrate to the core in very thick pieces, or, if air-hardening is to be adopted, metals should be employed which have a greater susceptibility to the penetrative effect of hardening.

[1] "Hardening in Heated Liquids"; *Bulletin de la Société de l'Industrie Minérale*, July 1913.

TABLE I.—*Analyses of the Steels investigated.*

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.
Carbon . . .	0·59	0·57	0·31	0·37	0·36	0·38	0·34	0·35	0·35	0·40	0·62	0·51	0·37	0·38	0·47
Silicon . . .	0·19	0·33	0·34	0·14	0·14	0·12	0·20	0·15	0·18	0·16	0·17	0·23	0·17	0·23	0·20
Manganese . .	0·54	0·60	0·46	0·26	0·20	0·19	0·28	0·21	0·22	0·24	0·61	0·38	0·57	0·36	0·36
Chromium . .	1·82	1·77	1·46	1·74	1·61	1·49	1·60	1·52	1·38	1·69	1·51	1·49	0·41	0·47	1·84
Nickel . . .	0·00	0·00	0·00	0·00	2·16	2·90	3·93	2·02	2·60	2·52	2·37	1·80	2·62	1·60	3·30
Copper . . .	0·00	1·15	0·00	4·14	0·00	0·00	0·00	2·40	2·15	4·04	0·00	1·00	0·00	1·40	1·24

These steels contain traces only of phosphorus and sulphur. They all underwent the transformation on heating below 775°. Quenched in water from a temperature of 790°, small parts showed Brinell hardnesses of 600 and upwards.

TABLE II.—*Influence of Copper on the Depth of Hardening in Chromium Steels not containing Nickel.*

Treatment.	Brinell Hardness Nos.			
	No. 1.	No. 2.	No. 3.	No. 4.
Cooled in still air from 790° on square bars 10 × 10 millimetres.	312	512	...	477
,, ,, ,, ,, 20 × 20 ,,	241	364	...	...
,, ,, ,, ,, 30 × 30 ,,	234	255	...	...
,, ,, in bundles of four bars 30 × 30 millimetres	...	...	...	269
,, ,, at 820° on square bars 10 × 10 ,,	340	555	...	477
,, ,, ,, ,, 20 × 20 ,,	255	512	...	477
,, ,, ,, ,, 30 × 30 ,,	261	255	...	302
,, ,, in bundles of four bars 30 × 30 ,,	...	...	...	269
,, ,, at 870° on square bars 10 × 10 ,,	555	555	207	555
,, ,, ,, ,, 20 × 20 ,,	444	600	...	512
,, ,, ,, ,, 30 × 30 ,,	321	600	...	512
,, ,, in bundles of four bars 30 × 30 ,,	...	...	...	444
Annealed at 820°	163	217	187	170

From this table it will be seen that the chromium steels not containing copper (Nos. 1 and 3) harden only with difficulty on cooling in air. Steel No. 3, even when quenched in the form of bars 10 millimetres square from a temperature of 870°, only possesses a hardness of 207.

Before steel No. 1 attains distinct hardening in air-cooled bars of 10 and 20 millimetres square section a temperature of 870° has to be reached. With bars 30 millimetres square air-quenching, even from 870°, is not very effectual.

On the other hand steels Nos. 2 and 4, which contain copper and chromium, when in bars of 10 millimetres section, become air-hardened when a temperature of 790° has been reached. Square bars 20 × 20 millimetres air-harden after heating to 820°, and bars 30 × 30 millimetres harden in air after heating to 870°.

In the case of steel No. 4 it has even been established that, on heating to a temperature of 870°, bundles of even four bars each 30 × 30 millimetres square can be effectually air-hardened.

It will be seen that the presence of copper does not prevent softening on annealing at a high temperature.

From Table III. it will be seen that the chromium-nickel steels not containing copper (Nos. 5 and 6), which soften well on annealing, do not possess the property, in thick pieces, of air-hardening.

Table III.—*Influence of Copper on the Depth of Hardening in Chromium Nickel Steels.*

Treatment.	Brinell Hardness Nos.					
	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.
Cooled in still air from 790° in bundles of four bars 30 × 30 millimetres square	269	321	387	340	418	477
Cooled in still air from 820° in bundles of four bars 30 × 30 millimetres square	286	321	418	402	477	512
Cooled in still air from 870° in bundles of four bars 30 × 30 millimetre squares	321	350	444	444	477	477
Annealed at 820°.	179	207	269	207	207	196

Steel No. 7, containing chromium and nickel but no copper, air-hardens well but does not soften well on annealing.

Steels 8, 9, and 10, containing chromium, copper, and nickel, air-harden even in thick pieces and soften well on annealing.

Table IV.—*Tensile and Shock Tests on Chromium Nickel Steels and on Chromium Copper Steels with or without Nickel.*

Steel.	Temperature of Tempering.	Elastic Limit. Kilogs. per Sq. Mm.	Tensile Strength. Kilogs. per Sq. Mm.	Elongation per Cent.	Resilience (Charpy Drop Weight).	Brinell Hardness Nos.	Grain of Shock Test Bar.
No. 2. Copper and chromium but no nickel.	450°	...	...	...	2·40	418	Crystalline.
	600°	...	...	...	12·86	302	Fibrous.
	650°	...	...	...	19·15	269	,,
No. 7. Chromium and nickel but no copper.	450°	not recorded	158·0	7·0	9·10	387	Crystalline.
	600°	91·0	102·3	15·0	18·30	286	Fibrous.
	650°	68·3	88·3	17·5	26·60	241	,,
No. 9. Chromium, copper, and nickel.	450°	not recorded	155·0	7·0	6·20	430	Crystalline.
	600°	98·4	107·0	11·0	11·90	302	Fibrous.
	650°	80·2	89·0	14·0	21·70	255	,,
No. 11. Chromium and nickel but no copper.	450°	149·0	164·1	5·0	2·40	418	Crystalline.
	600°	107·8	125·7	10·0	7·20	340	Crystalline and fibrous.
	650°	91·7	109·0	13·0	15·60	302	Fibrous.
No. 12. Chromium, copper, and nickel.	450°	not recorded	166·2	4·0	4·30	431	Crystalline.
	600°	104·2	112·4	10·5	18·30	302	Fibrous.
	650°	...	...	...	25·80	269	,,
No. 13. Chromium, nickel, and copper	450°	not recorded	130·9	7·0	13·80	340	Coarse crystals.
	600°	78·6	90·8	13·5	24·2	255	Fibrous.
	650°	...	...	...	33·2	228	,,
No. 14. Chromium and copper but no nickel.	450°	132·3	134·6	7·0	9·1	340	Crystalline.
	600°	85·5	96·4	11·0	24·2	286	Fibrous.
	650°	...	...	...	28·3	228	,,
No. 15 Chromium, copper, and nickel.	200°	not recorded	219·0	6·0	...	...	...

The penetrative effect of quenching on the steels, particulars of which are given in Table IV., is not the same in all cases. Nevertheless it is sufficiently strong to enable the effect of heat treatment to be completed at some depth, and the results may be considered fairly comparable.

Steels Nos. 2, 7, 9, 11, 12, 13, and 14 were tested in bars 160 millimetres long, cut from a forged bar of 30 × 30 millimetres square section. After treatment they were either notched for the resilience tests (the notch being a round one of 8 millimetres diameter) or machined to round bars 13·8 millimetres in diameter and 100 millimetres long between punch marks, for the tensile tests. The elastic limit was determined roughly by observing the slowing down in the rate of the rise of the mercury column. The Brinell hardness was ascertained by means of a ball 10 millimetres in diameter at a pressure of 3000 kilogrammes and applied to the surface of the bars used for the shock tests.

Both the shock and tensile test-pieces were quenched, from a temperature of 800°, in oil at about 50°. They were kept for about half an hour at the tempering temperature, after which they were quenched in cold oil.

As an exception the tensile test-piece of steel No. 15 was taken from a forged round of 20 millimetres diameter. It was completely turned down, before testing, to a diameter of 13·8 millimetres. It was cut to 100 millimetres length between punch marks and after machining was quenched from 800° in oil at 150° and tempered for one hour at 200°.

The tests shown in this table show the properties of steels containing copper to be practically the same, both on quenching and tempering, as those of steels not containing copper.

DISCUSSION.

Dr. J. O. Arnold, F.R.S., Member of Council, said he had read Mr. Grenet's paper with very great interest, but it seemed to him that he had omitted to consider two very primary questions in connection with the action of copper and nickel on pure iron. In the steels mentioned it had to be remembered that only the chromium was acting with the carbon; there was no carbon with the nickel or with the copper. Speaking in round numbers which were readily remembered, taking pure iron, or at any rate steel, of 0·1 per cent. of carbon, and adding 7 per cent. of nickel to it, if 28 per cent. of nickel were added practically the same mechanical tests were obtained, about 38 tons; but if 14 per cent. of nickel was added the stress went up to 90 tons, with very good reduction of area, 45 per cent., so that at that point there was either a saturated solution of nickel in the iron or a nickelide of iron which corresponded to the percentage—13 per cent. really—Fe_7Ni; so that really in the steels the nickel was associated only with the iron and not with the carbon at all. The case of copper was even more interesting. In 1894 he had the honour of reading before the Institute a paper on the influence of elements on iron, and the case of copper was a very astonishing one. Taking nearly pure iron and adding 2 per cent. of copper, which was supposed to be a poison at that time, it rolled very perfectly, and the 2 per cent. of copper raised the maximum stress of the iron from 21 to 34 tons per square inch, and raised the elastic limit from about 11 or 12 to 30. In the work he had since done the copper seemed to dissolve pretty readily in the iron to 2 per cent. He wished to call the attention of the Institute to some very interesting experiments he had made some time ago on copper welding, which had the remarkable effect that the weld was the strongest part of the metal. Between two plates of very mild steel was placed a very thin strip of electrolytic copper; they were clamped together and put into a crucible, in coke dust moistened with a solution of sugar in order to get the CO atmosphere, and at a temperature of 1100° in about two or three hours the film of copper dissolved completely in the steel. Assuming on the weld there was about 2 per cent. of copper, there were several more tons strength in the weld than in the other part of the steel. It was a very interesting process. The copper as such disappeared, and under the microscope all that could be seen was a slight blueing when the specimen was polished, and that was the solid solution of the copper and the mild steel. Therefore it seemed to him, in connection with Mr. Grenet's paper, that there was a very complex problem: the astonishing influence of the copper and the nickel itself on the iron, independent altogether of the carbon.

Dr. W. H. Hatfield (Sheffield) said the paper was an extremely interesting one from the standpoint from which Mr. Grenet had been

experimenting with copper with a view to seeing how far it would replace nickel. Mr. Grenet and the value of his work were well known, and his paper presented an extremely careful piece of work, covering an important field—a work which would probably save many other metallurgists from making a similar investigation.

Dr. C. H. DESCH (Glasgow) said there was one criticism he would venture to make on Mr. Grenet's paper, and that was, that in the absence of photomicrographs there was no evidence that what had been measured was the actual penetration of the hardening. The results were obtained by determining the Brinell hardness and the softening taking place on annealing the specimen afterwards. The hardening of case-hardened surfaces depended on two factors—the rate of combination of carbon with the iron or other elements present, and the rate of diffusion inwards. If there was a rapid rate of combination, with the formation of a large quantity of carbide at the surface, a hard surface would be obtained, whilst the penetration might be comparatively small. On the other hand, the rate at which the carbides diffused into the metal would be very much affected by the presence of solid solutions such as those to which Professor Arnold had referred. One would scarcely expect, without having made experiments, that the presence of copper in solid solution would favour the diffusion of carbide inwards; one would rather think that the carbide would diffuse less inwardly in the solid solution containing copper than it would in iron free from other elements. The case of chromium and nickel was different, because there there was the possibility of carbides forming in solid solution, but copper did not form carbide in solid solution. It therefore would have been interesting to know whether the actual microscopical examination confirmed the statement that there was absolutely a greater depth of penetration in the case of copper.

CORRESPONDENCE.

Mr. L. GRENET (Firminy), writing in reply, thanked Drs. Arnold, Hatfield, and Desch for the observations they had made on his paper. The object he had had was strictly practical and did not seek to determine the distribution of the copper in the phases which constituted the steel. The penetration of the copper in any alloy depended on the conditions which prevailed during the decomposition, by cooling, of the phase or phases which constituted the alloy at high temperatures. In the case of steels, the composition of the gamma phase (stable state on heating) was that of the steel. The fact that in a steel in the stable state in the cold, an element like, for example, copper, formed part either of the alpha, or of the carbide phase, had up to now no known relation with the influence of that element on

the temperature of the transformation on cooling, and consequently on the depth of the penetration of the hardening effect. The special elements introduced into the steel increased the depth of the penetration of the hardening effect, whether they formed part of the carbide phase or of the alpha phase. In these circumstances the microscopic examination of the steel in the "stable state on cooling" could not furnish any direct indication whatever as to the influence of any given element on the depth of penetration. He (Mr. Grenet) would not deny the interest attaching to such an investigation, but in the existing state of knowledge it was not one that could achieve the object he had had in view.

The fear that the hardness of the samples would not be the same at the surface as it was at the centre would be well founded were it a matter of very energetic quenching during which the surface would be cooled very appreciably quicker than the centre, but in the specimen air-quenching was employed and numerous experiments had shown that in the conditions under which they were performed the centre-hardness was practically the same as the surface hardness, and that the differences are, in all the instances in which they occur, too slight to affect the conclusions. He had always accompanied his experiments on the depth of penetration of the hardening effect carried out in the manner described, with magnetic measurements, made with the greatest care, of the temperature at which the cooling transformation and the hardening took place.

The research did not pretend to be complete, as the author confined himself to steels capable of considerable depth of penetration on hardening. It should not be concluded that the action of copper by itself was negligible because the chromium-nickel steels mostly used in practice did not air-harden in the case of bars of 10 millimetres square, and yet had a depth of penetration far superior to that of the carbon steels. The action of copper by itself, although it did not enter into the scope of the investigation, was nevertheless exceedingly interesting from a practical point of view. The distribution of the copper in each of the phases of a steel in the stable state on heating, likewise formed a subject of great interest and one worthy of investigation. In conclusion he hoped, with Dr. Hatfield, that other investigators would continue the research.

NOTES ON SOME QUENCHING EXPERIMENTS.

By LAWFORD H. FRY (Burnham, Pa., U.S.A.).

The experiments to be described were carried out to study the rate of cooling in various quenching media, and to try to connect the rate of cooling with the physical properties obtainable in quenched and tempered forgings.

The main series of experiments was carried out with two locomotive driving axles, which were drilled so that a pyrometer could be inserted and the temperature of the axle measured continuously during the process of quenching. One axle was 11 inches in diameter, was forged solid, and weighed 1830 lb. The other axle was 12 inches in diameter, bored longitudinally with a 3-inch hole, and weighed 2000 lb. To measure the temperature, a hole for a pyrometer was bored in one end of each axle to a depth of about 15 inches parallel to the longitudinal axis. In the solid axle the hole was half way between the centre and the outside of the axle, while in the bored axle it was half way between the surface of the bore and the surface of the axle. The pyrometer used was a base metal thermocouple fitted with a plug which was driven into the outer end of the hole so that the quenching medium could not enter and the actual temperature of the interior of the axle could be measured. In carrying out the experiments the axle was heated uniformly as though for quenching in the usual course of manufacture, then withdrawn from the furnace and the pyrometer inserted. A wait of about two minutes was made for the thermocouple to take the temperature of the axle, and the axle then quenched. As the temperature fell readings were taken at short intervals, and temperature time curves were plotted as in Fig. 1. The quenching media experimented with were air, water, a heavy oil of 26°, a light oil of 29° Beaume gravity, and three strengths of a cutting compound dissolved in water. This cutting compound, which was composed of mineralised lard oil and soft soap, was first used in a 50 per cent. solution, that is, equal parts of compound and water. It was then diluted to a 33 per cent. solution, that is, one part

compound to two of water, and was finally diluted to a 25 per cent. solution, one part compound to three of water. The cooling curves for twelve experiments are given in Fig. 1, eight being made with the solid and four with the bored axle, as shown below:

Number of Curve on Plot.	Kind of Axle.	Quenching Medium.
1	Solid axle	Air
2	"	Heavy oil
12	"	Light oil
10	"	Water
6	"	50 per cent. solution
4	"	50 " "
5	"	33 " "
7	"	33 " "
3	Bored axle	Heavy oil
9	"	33 per cent. solution
8	"	25 " "
11	"	25 " stirred by air

These curves permit comparisons between the rates at which the various media abstract heat, and also throw some light on the influence which the form of the object quenched has on its rate of cooling.

Influence of Form of Object on Rate of Cooling.

It is obvious from the curves that the bored axle cooled more rapidly than did the solid axle in the same medium. This is due to the greater surface exposed to cooling for each pound of weight. A direct comparison of the two axles is facilitated by Tables I. and II., which also include particulars of some experiments in which the cooling rate of a small test-piece was measured.

Table I.—*Comparative Dimensions of Test-Piece and Axle.*

Object.	Diameter. Inches.	Length. Inches.	Weight. Lb.	Surface. Sq. Ins.	Surface in Sq. Ins. per Lb. of Weight.	Heat Capacity in B.Th.U. per Degree of Temperature per Sq. In. of Surface.
Test-piece . .	1¼	5	1·6	22	13·5	0·0085
Bored axle . .	12	65	2000	3270	1·63	0·070
Solid axle . .	11	66	1830	2540	1·39	0·082

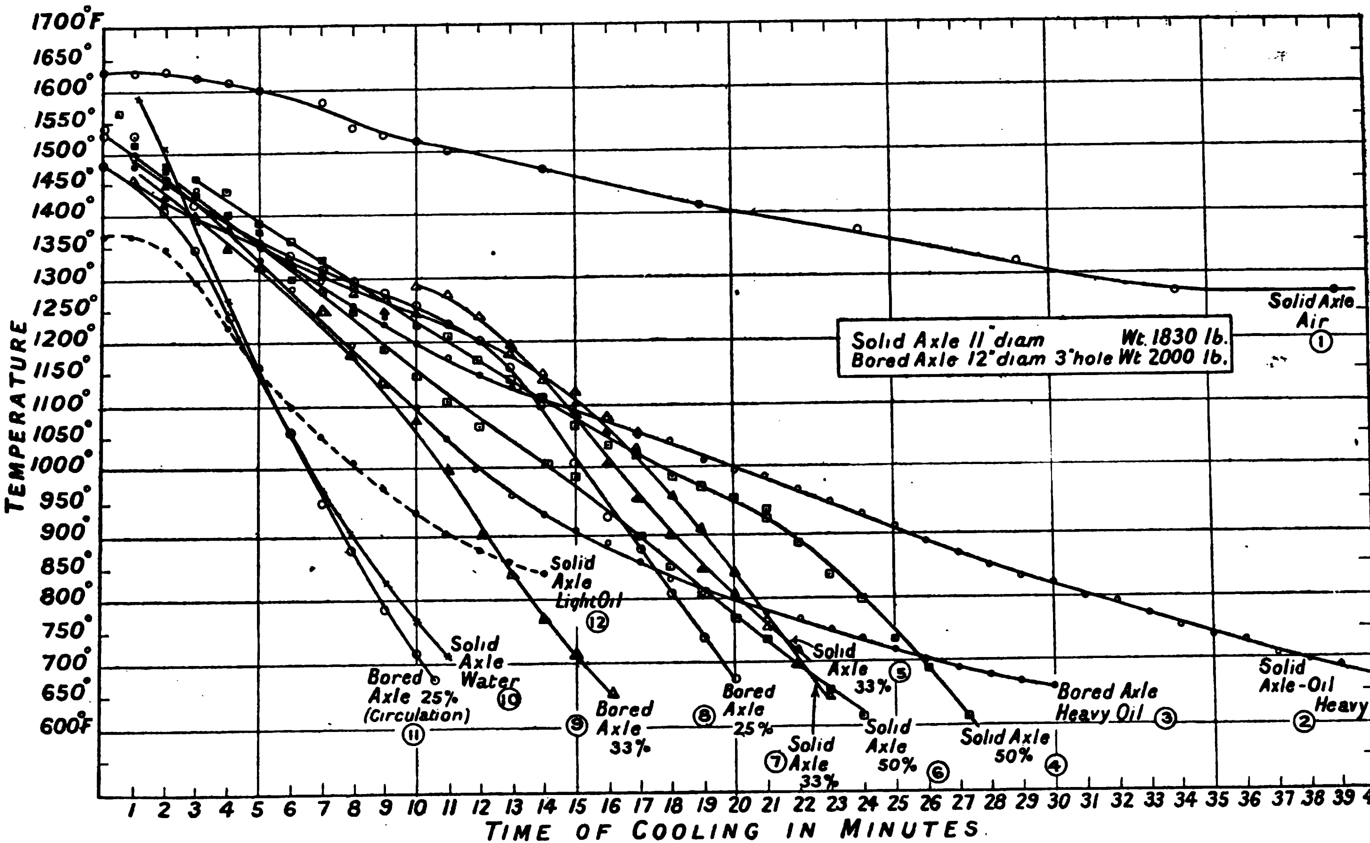


FIG. 1.—Rate of Cooling of Axles in various Quenching Media.

This test-piece was 1¼ inch in diameter by 5 inches in length, with a weight of 1·6 lb. A hole drilled in one end along the axis enabled a thermocouple to be inserted at the centre of the piece. Cooling curves while quenching in various media were taken in the same way as was done for the axles, and figures derived from these curves are given in Table II. Dimensions of test-piece and axles are given in Table I., from which it appears that the test-piece had practically a ten times greater surface per pound of weight than the solid axle, the figures being 13·5 and 1·39 square inches per pound, while the rate at which the test-piece lost temperature in a given medium was very close to ten times that at which the axle cooled (see column 7, Table II.).

TABLE II.—*Cooling Rates in Various Media.*

1.	2.	3.	4.	5.	6.	7.	8.
		Fall of Temperature.				Rate of Cooling.	
Cooling Medium.	Object Cooled.	From Degree F.	To Degree F.	Drop Degree F.	Time of Cooling in Minutes.	Degrees per Minute.	B.Th.U. per Sq. In. of Surface per Minute.
Air	Test-piece	1450	1290	160	1·3	120	1·0
„	Solid axle	1450	1290	160	16·0	10	0·8
Heavy oil	Test-piece	1460	850	610	1·7	350	3·0
„	Bored axle	1450	850	600	15·5	39	2·7
„	Solid axle	1450	850	600	26·0	23	1·9
Cutting compound	Test-piece	1450	800	650	1·3	500	4·2
„	Bored axle	1450	800	650	16·0	40	2·8
„	Solid axle	1450	800	650	18·0	36	3·0
Water	Test-piece	1450	700	750	0·9	820	6·9
„	Solid axle	1450	700	750	9·0	82	6·8
Light oil	Solid axle	1350	850	500	11·5	44	3·6

This means that in a given medium the heat is given up by the axle and by the test-piece at practically the same rate in British thermal units per square inch of surface. The closeness with which this holds can be seen from column 8 of Table II. When the great difference in size of the object is taken into considera-

tion, the fact that the cooling rates are so nearly the same is remarkable. It seems that fairly accurate information as to the quenching properties of a medium can be obtained from small scale experiments.

In any such work it must of course be remembered that the physical properties of steel are determined not by the rate at which the heat is lost per unit of surface, but by the rate at which heat is lost per unit of weight, that is by the rate at which temperature is lost. Referring to Table II., the rate at which heat is lost per unit of surface (column 8) is determined by the quenching medium, while the physical properties of the steel are determined by the rate at which the temperature is lost (column 7). This rate of temperature loss depends both on the quenching medium and on the form of object quenched, the latter being the more important factor.

This being the case it is necessary, in any discussion of the physical properties of steel in connection with heat treatment, to define not only the cooling medium, but the size of the piece cooled. This point was made by the author before the American Society for Testing Materials in June 1916, and is also dealt with in Stead's recent paper on "Mechanical Properties of Steel." The only scientific method of defining heat treatment in connection with physical properties is not to speak of "water quenching" or "air cooling," but to give the rate of temperature loss over a given range, as is done, for example, by Howe and Levy in their "Notes on Pearlite." [1]

To appreciate the indefinite nature of the expression "air cooled" it is only necessary to compare the cooling rates of the test-piece and the axle in Table II. The test-piece lost heat at the rate of 120° per minute, and although the rate of cooling would be somewhat slower if it were averaged over a longer temperature range so as to include the recalescent period, it will be seen that the rate at which the test-piece cools in the air is of the same order as the rate at which the axle cools when quenched in water. Consequently the physical properties of the "air cooled" test-piece and of the "air cooled" axle will differ as widely as the properties of the air-cooled axle and of the water-quenched axle.

[1] *Journal of the Iron and Steel Institute*, 1916, No. II. p. 210.

Quenching Speed and Composition of Medium.

Heavy Oil.—Curves 2 and 3, Fig. 1, show respectively the cooling rates for the solid and the bored axle and do not call for individual comment.

Cutting Compound.—The curves for the solid axle, Nos. 4, 5, 6, and 7, fall very much together. They indicate that the dilution of the cutting compound by water has little effect on its quenching properties. The same thing is shown by the physical properties obtained. There is more difference between two quenches with the solution containing 50 per cent. of oil than there is between the average of the quenches in the solution containing 50 per cent. and the average in that containing 25 per cent. The two curves for the bored axle, Nos. 8 and 9, do not conflict with the foregoing. In fact in the 33 per cent. solution the cooling was considerably more rapid than in the 25 per cent. solution. Tensile tests from the two axles represented by these curves, after being drawn at 1100° F., gave the following results:

No. of Curve on Plot.	Quenching Medium.	Minutes to Cool from 1450° F. to 700°.	Elastic Limit.		Tensile Strength.		Elongation in 2 Inches.	Reduction of Area.
			Lbs. Sq. In.	Tons. Sq. In.	Lbs. Sq. In.	Tons. Sq. In.		
	Per Cent. Solution.						Per Cent.	Per Cent.
8	25	16·1	40,500	18·1	78,000	34·8	29·0	55·0
9	33	13·6	43,000	19·7	81,500	36·4	30·0	53·5

These figures suggest that the axle giving curve No. 9 did, for some reason, cool more rapidly than that of curve No. 8. It is possible that the explanation is to be found in some local condition affecting the convection in the bath.

Curve No. 11 is made from the same axle and the same 25 per cent. quenching medium as used for curve No. 8, but a jet of compressed air was introduced into the bath so as to give a vigorous circulation to the quenching medium. The effect in increasing the rapidity of cooling is very marked. The time required for the temperature to fall from 1450° F. to 800° F. was reduced from sixteen minutes with the bath stationary to nine minutes with the bath agitated by air, the rate of temperature

fall being increased from 40° to 72° per minute, that is, by 80 per cent. The physical properties show a corresponding improvement. The following figures show the tensile properties obtained with carbon steel and with chrome vanadium steel axles quenched in the 25 per cent. solution first without agitation and second with agitation.

Type of Steel.	Condition of Bath.	Temperatures.		Elastic Limit.		Tensile Strength.		Elongation in 2 Inches.	Reduction of Area.
		Quench.	Draw.	Lbs. Sq. In.	Tons. Sq. In.	Lbs. Sq. In.	Tons. Sq. In.		
Carbon .	Still	1500° F.	1150° F.	49,500	22·09	95,000	42·41	20·5	43·5
,,	Agitated	500° F.	1150° F.	68,800	30·89	105,300	47·90	21·0	42·0
Chrome Va.	Still	1500° F.	1150° F.	80,500	35·93	123,500	55·13	20·5	57·5
,,	Agitated	1500° F.	1150° F.	96,000	42·85	124,000	55·35	16·5	61·5

Water.—Curve 10 shows the cooling of the solid axle in water. The temperature is lost at a rate slightly faster than in the case with the bored axle in the cutting compound with air circulation.

Taking the results in general the rates of cooling of the solid axle weighing 1830 lb., and having about 1·4 square inch per pound of weight, may be given in round figures as follows:

	Degrees Fahr. per Minute.
In air	10
In heavy oil, 26° B.	25
In oil solution	35
In light oil, 29° B.	45
In water	80

The experiments are not complete enough to establish a complete theory of quenching action, but one appears to be justified in concluding that for rapidity of cooling it is necessary to have:

(*a*) Intimate contact between fluid and object, to permit transfer of heat from object to fluid.

(*b*) Free flow of fluid to remove heated or vaporised fluid from the surface of object.

The effective quenching given by water is due to a combination of these two factors, aided doubtless by its high specific heat and high latent heat of vaporisation. It appears, however, that the high heat-absorbing capacity of water can be offset

if intimate contact between water and object is hindered, as in the case of the cutting compound. Here, although 75 per cent. of the quenching medium is water, and the viscosity is low, allowing free convection, the quenching rate is less than half that of water, so long as no forced circulation is provided. It is known that an oil film on the heating surface of a boiler will reduce the transfer of heat to the water, and it seems probable that a similar effect prevents the transfer of the heat to the bath from the object to be quenched.

The great acceleration in cooling produced by a forced agitation of the solution is noteworthy. It is not certain how far the same action can be obtained with a pure oil such as the light oil of curve 12, but the author hopes to be able to carry out further experiments to settle this question.

The more rapid cooling produced with the light oil in comparison with the heavy oil is evidently due to the greater fluidity of the former, which enables more rapid convection currents to be set up and to carry off the heat.

DISCUSSION.

Dr. C. H. DESCH (Glasgow) wished to emphasise the extreme importance of Mr. Fry's results. When the behaviour of a particular steel was described, data were given as to its heat treatment, and it was usually stated that it was quenched from such and such a temperature in water or oil, as the case might be, but, as the paper clearly showed, in the absence of definite statements as to dimensions, that might be meaningless. If the specimens taken for examination had been cut from an object of unknown size, it was not possible to know to what heat treatment it had been subjected, and Mr. Fry's paper called attention to the need of very accurate specification when the properties of heat-treated metals were being described.

Dr. W. A. BONE, F.R.S. (London), said there was one point with regard to Dr. Fry's paper which Dr. Desch had not referred to. He had not had time to read the paper in detail, and perhaps his criticism might not be a valid one, but he would like to mention it. The paper dealt really with a question of heat flow across a series of concentric cylindrical shells of metal, and he gathered from the paper that it had been measured by the insertion of a pyrometer thermo-junction into only one of these concentric cylindrical shells (sketch). Heat actually flowed from a higher temperature, T, at or near the centre through a gradient down to a lower temperature, $t°$, at the periphery, where the cooling agent was applied. He thought Mr. Fry was assuming that the temperature measured at the selected point represented the mean temperature of the mass of the whole piece. An examination from the point of view of heat alone would show that was quite an arbitrary assumption in the present case, and he really did not know what the meaning of Mr. Fry's curves might be. That criticism might be valid or might not, but he thought it important that the point should be definitely put to Mr. Fry by some one in correspondence.

CORRESPONDENCE.

Dr. A. MCCANCE (Glasgow) wrote that the results of Mr. Fry's experiments carried out on an industrial scale were valuable, and indicated what could be done to fix the quenching power of different liquids. It was a matter which could not be decided by any physical examination, however complete—the conditions during quenching were far too complex to admit as yet of any theory of quenching *per se*; but happily it was a matter simple enough to determine just how long

a mass of steel took to cool down between definite temperature limits after heating and immersing in a bath of liquid, and it was easier to do this with large masses of steel than it was to do so in the laboratory.

He (Dr. McCance) had already shown that the rate of cooling through the change point at 700° C. was the important criterion of the quenching power, and for practical purposes the velocity of cooling through the range 700° to 600° C., expressed in degrees per second, gave a standard by which different liquids could be compared. It was advisable to keep a standard temperature of quenching such as 800° or 850° C., and a standard size of bar, preferably a solid round about 10 inches diameter and 40 inches long, which was dipped vertically with a pyrometer at the centre of the bar.

In this connection he would remind Mr. Fry that the results for his solid and his bored bars were not strictly comparable, since the pyrometer had not been placed in a similar position in both. In the solid bar it was 2¾ inches from the outside surface while in the bored bar it was 2¼ inches. This gave an advantage to the bored bar in quick cooling, and consequently the results were not quantitatively comparable one with the other, though they were probably near enough when the general accuracy was considered.

Another factor which was most important if comparisons were to be carried out, was that the quenching liquid must be circulated, otherwise vapour sheathes would form round the steel and prevent proper heat abstraction. This effect gave rise to cooling curves of the type shown in Fig. 1, and brought about unequal quenching and especially warping. Mr. Fry's curves, Nos. 7 and 8, showed this effect, and thus spoiled any deductions which could otherwise have been drawn from them. He was inclined to account for it as being due to oil films on the surface of the bar, but the temperature of the bar would vaporise the liquids near the outer surface, and this vapour was a far more efficient insulator than any kind of oil film would be.

A method which he (Dr. McCance) had used for determining the hardening power of liquids was to quench a standard bar containing about 0·9 per cent. carbon in the liquid and to compare its electric resistance with that of the same bar quenched in water, the ratio of the differences between the quenched and annealed bar for the liquid and for water giving a measure of the hardening power. It was not strictly accurate, but it could be determined quickly and was sometimes useful.

He was able to corroborate from his own experience the effect of the rate of cooling on the mechanical properties, and he would look forward to the results of the further experiments which Mr. Fry hoped to carry out.

The author's reply to the verbal discussion on his paper was unfortunately received too late for inclusion here, and will be found printed on p. 279 at the end of the other papers.—[Ed.]

CEMENTATION BY GAS UNDER PRESSURE.

By F. C. LANGENBERG (Harvard University).

INTRODUCTION.

With the exception of the brilliant work of Giolitti, very little has been done on the subject of cementation or decarburisation under pressure. The work by Giolitti is too well known to require discussion. In his work a furnace was employed which had several defects, namely, the inability to maintain a constant temperature, probably due to the lack of any cooling provision for the jacket, and the inaccessibility to the interior.

The author of this paper feels that a description of the pressure furnace which has been developed in the Harvard University Metallurgical Laboratory will be justifiable, as some of the defects encountered in the use of former furnaces have been overcome. The experimental results herein presented it is hoped will be of some interest in themselves. It is realised that they are far from complete, but it is hoped that additional data may be presented at a future date.

Acknowledgments.

The author wishes to express his sincere appreciation for the assistance rendered by the following gentlemen: Professor Albert Sauveur; Professor H. L. Smyth; Professor Chas. H. White; Dr. H. C. Hayes, Instructor in Physics, Harvard University.

The author is especially indebted to Professor Albert Sauveur for his encouragement and frequent suggestions in the course of this investigation; to Professor H. L. Smyth, whose deep interest in the subject made it possible to secure the necessary funds to carry on this work; to Professor Charles H. White, for his suggestions and assistance in the analytical work necessary in this investigation; and to Dr. H. C. Hayes, for the loan of certain patterns and his many valuable suggestions in the construction of the furnace used.

Description of Apparatus.

Dr. Hayes, of the Jefferson Physical Laboratory of Harvard University, developed a furnace which, in the author's opinion, could be made useful for cementation work under pressure if properly modified. Through the kindness of Dr. Hayes it was possible to undertake the construction of a furnace similar to the one used by him, and the one herein described is a modified form of that furnace. The essential features are similar, but such improvements have been made as were necessary to make the apparatus suitable for metallurgical experiments.

Financial conditions made it necessary to cut down the dimensions of the proposed unit, as originally planned and shown in the accompanying sketch (Fig. 1), but the proportions were not disturbed nor was the usefulness of the apparatus seriously impaired.

The attempt has been made in the construction of the furnace to combine all the requirements of a vacuum and pressure furnace into a single unit, and at the same time to do so as economically as possible. A short description will give an idea of the furnace proper.

The heating unit consists of an alundum tube, threaded on the outside, nine turns to the inch. On this tube is wound No. 16 nichrome wire, which gives a total coil resistance of 10 ohms.

A mixture of alundum cement and water was then prepared, which was firmly pressed on over the wire, to a thickness equal to that of the tube itself. This was dried and then baked at a high temperature for several hours. An asbestos steam pipe cover of the proper length was then reamed out so as to fit very closely over the cemented tube. Finally a layer of asbestos felt was wrapped tightly over the pipe cover. In the section, Fig. 1 (starting from the inside and moving outward), can be seen, (1) the alundum tube threaded to receive winding, (2) layer of alundum cement, (3) asbestos pipe cover, (4) asbestos felt.

The heating unit was assembled as follows. Cast iron end plates were made which have two circular projections on their inner surface. The ends are held in place by four tie rods, none of which appears in the section. As can be noticed in Fig. 1 the alundum tube fits into the first projection, and the outside

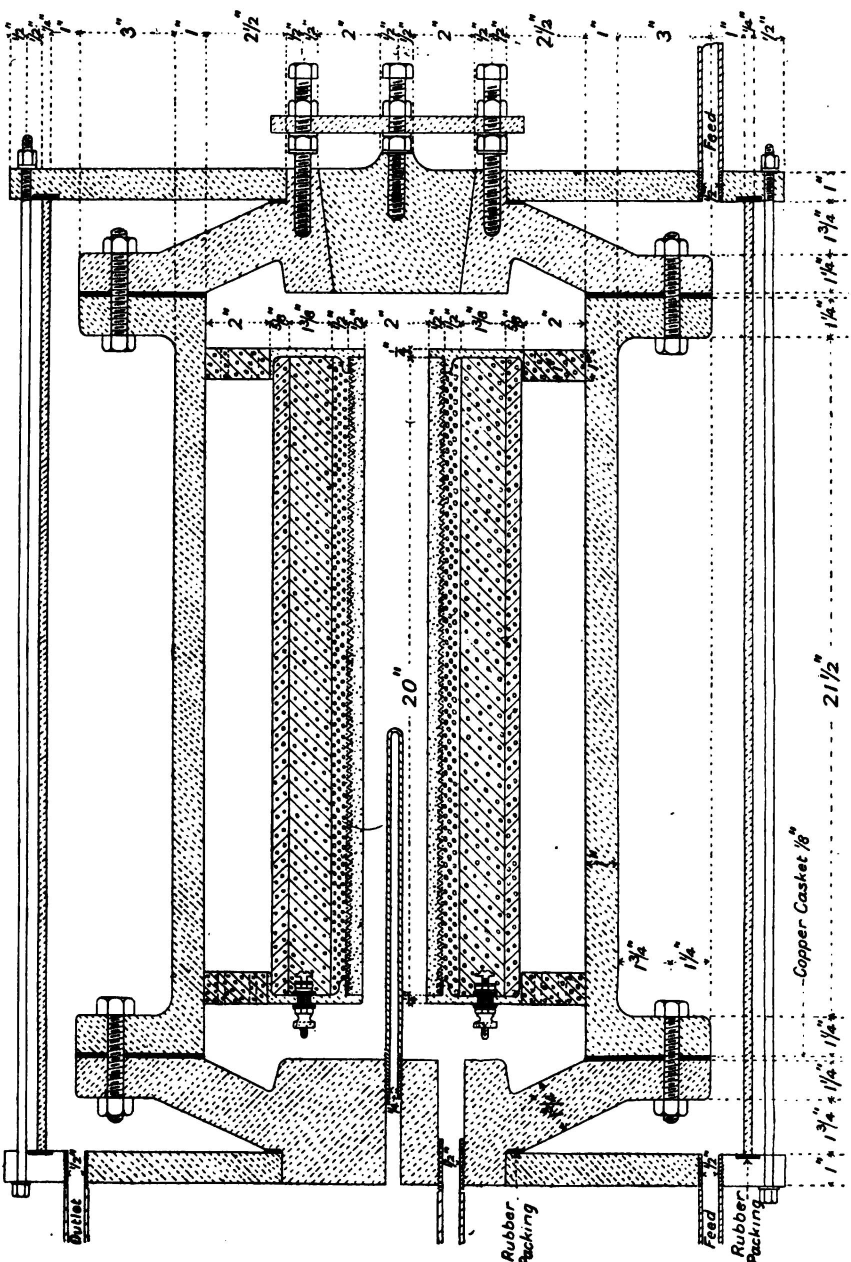


Fig. 1.—Vacuum and Pressure Furnace.

flange fits snugly over the outer layers of asbestos felt. The terminals of the nichrome winding are brought out to two binding posts, which are insulated from the cast iron head by mica tubes and washers. This method of assembling gives a very strong and convenient heating unit for any sort of furnace work not exceeding 1100° C. when used in an oxidising atmosphere.

As previously stated, the total resistance of the winding is about 10 ohms. When thrown across a 110-volt line, a temperature of 1100° C. is attained in ten minutes. If so large a current is allowed to continue, the coil will soon reach a temperature which will be destructive. It has been determined that 6·6 amperes will supply energy at a rate equal to the loss by radiation at 1000° C. (pressure being atmospheric). All that is necessary in the operation of such a furnace is to determine the temperature maintained by a certain energy supply. A number of such determinations similar to the one above were taken and a curve drawn between the points thus obtained. With a constant line voltage the control is very simple.

In starting full load can be thrown on, and when the desired temperature is reached external resistance can be introduced to reduce the energy input to the predetermined value taken from the curve.

The utilisation of the heating unit as a vacuum or pressure furnace is accomplished by inserting it in a steel jacket (see Fig. 1). The furnace proper is supported in the jacket by two asbestos wood rings, one at each end. These supporting rings are perforated with a series of holes to allow free circulation of gases.

The jacket is 1 inch in thickness and consists of a cylinder with flanges at the ends to which are bolted the heads. The joint between heads and cylinder is secured by a suitable gasket. Fig. 1 shows copper gaskets $\frac{1}{8}$ inch thick, but it was found later that a better fit could be maintained by the use of an asbestos-graphite gasket $\frac{1}{16}$ inch in thickness. All bolts are $\frac{1}{2}$ inch in diameter, standard thread.

The heads, front, and back are shown in section, Fig. 1. The rear head was tapped and threaded for spark plugs, through which current is carried to supply the heating unit. This device has proved simple and effective. Spark plugs were chosen with strong central leads and connections made internally to the

binding posts of the furnace and externally to the supply circuit. There is no danger of the furnace grounding on the jacket, and the plugs insure gas-tight, electrically insulated connections.

The rear head was also tapped and threaded for ½ inch double thick pipe, through which connections can be made to the pressure and vacuum pumps. The rear head was also tapped and threaded to receive a pipe in which the thermo-couple is inserted. This pipe is shown in position in Fig. 1. It had a very serious drawback in that the furnace had to be completely torn down for the insertion of a new pipe. This was overcome by a very simple device. A steel plug was turned from 2-inch stock and provided with 1-inch standard thread. The plug was then tapped and threaded to receive pipe which was to hold the thermocouple. The hole in the head was then enlarged to receive the plug carrying the pipe. It was then a very simple operation to remove this plug and insert a new pipe without disturbing the furnace in the least.

The front head of the furnace was cast from the same pattern as the rear one. The arrangement of the conical plug which forms the working door of the furnace is shown in section in Fig. 1. The plug was cast and turned down to a good machining fit, after which it was ground to an accurate fit by first using emery, then tripoli powder, and finally jewellers' rouge.

The plug fits so securely in its seat that some device is necessary to remove it. The three-bolt system shown in section in Fig. 1 was not successful. It consisted of three bolts, one screwed into the plug, and two others screwing into the furnace jacket, all provided with two nuts, one above and one below the strap. When one desires to remove the plug the two top nuts on the bolts fastened to the jacket are unscrewed, and then by unscrewing the two under nuts on the same bolts outward pressure is exerted on the strap, which in turn is transmitted to the plug by the centre bolt. When operating under vacuum the plug does not have to be held in place, as the external air pressure is sufficient. When operating under pressure the plug is held in position by tightening the outside nuts on the bolts in the jacket.

As stated previously, this means of removing the plug was not satisfactory, for the obvious reason that no twist could be exerted on the plug. To overcome this a new plug strap was made which

was considerably longer. The extremities of the strap were tapped and threaded for $2\frac{3}{4}$-inch set-screws of sufficient length to bear on the jacket head. To remove the plug, all that is necessary is to loosen the two outside nuts on the bolts which screw into the jacket, and then tighten up the set-screws. If this does not bring out the plug the arm can be revolved, and with the set-screws well tightened a twisting pull is exerted which always removes with ease the plug from its seat. Circulation under pressure inside the jacket is provided for by inserting a pipe into the conical plug fitted with two valves. Two valves were used as it gave a more delicate control of the amount of gas passing from the furnace when operating under high pressures.

The cooling of the jacket is accomplished by the thermo-siphon system of oil circulation. The cooling jacket was made by two cast heads (shown in section, Fig. 1) and a section of steel pipe of the proper length and diameter, assembled by tie rods and the necessary gaskets. Rubber gaskets have been used with perfect satisfaction, and no difficulty is experienced in making tight joints. The inlet is at the bottom and the outlet at the top, connection being made to a galvanised iron tank, used as a radiator and oil reservoir. A drainage tap is provided at the bottom for removing the oil when necessary.

The installation for pressure work consists of the following appliances : motor, compressor, storage tank, pressure gauge, and the necessary valves. The motor is a Holtzer Cabot $\frac{1}{3}$ horse-power at 1200 revolutions. It is belted to a short line shaft to which in turn are belted the vacuum pump and compressor. The compressor was made by H. G. Crane, of Brookline, Mass., and consists of two cylinders, air cooled, operating at 500 strokes per minute. The clearance has been reduced to a minimum and high pressures can easily be reached in a short time. The exhaust from the compressor is piped to a storage tank (in cabinet under bench), and from the tank to the inlet in the furnace provided for pressure. Valves were inserted in the line between the furnace and gauge, between gauge and tank, and between tank and pump. These various valves make it possible to read either the pressure in the tank or the pressure in the furnace. The pressure gauge is of the Crosby type, reading in pounds, the one in use at present having a limit of 300 pounds.

The vacuum pump is an oil-sealed, plunger type. It has two cylinders, 5-inch stroke by 2-inch bore, connected in series, one cylinder having its intake connected to the exhaust of the other cylinder. The vacuum gauge is of the McLeod type, so constructed that 1 millimetre difference in level in the mercury column gives a vacuum measurement of 0·00875 millimetre of mercury. An ordinary dial type of vacuum gauge is also used to give approximate readings while the furnace is being exhausted. All exhausted air is thoroughly dried by $CaCl_2$ and P_2O_5 tubes before entering the pump.

The electrical control of the furnace and motor is centered on one board. At the top is the line switch and fuses. Below and on each side are switches, one operating the furnace circuit and the other the motor. An ammeter which is in the furnace circuit is also placed on the board. The starting rheostat for the motor is mounted below the ammeter. Terminals are provided at the base of the board for connecting the furnace, rheostat, and motor.

The thermocouple for measuring the furnace temperatures is enclosed in a fused quartz tube which fits snugly into the iron pipe already described. A platinum platinum-rhodium couple is used, its electromotive force being measured by a Leeds and Northrup portable potentiometer. The cold junction can be maintained at zero by an ice-box shown in the photographs. This arrangement allows of temperature readings with an accuracy of 5° at 1000° C.

The cycle of operations when the unit is operated as a vacuum furnace is something as follows. After the desired charge has been made the plug is inserted and the valve next to the furnace in the pressure line is closed. The valves in the vacuum line are opened and the pump started. In about ten minutes the vacuum will be less than 0·1 millimetre of mercury. The heating current is then turned on and the furnace brought to the desired temperature, which can easily be maintained by keeping the current constant. The pump is run continuously to take care of gases evolved from the specimens during heating, and the slight leakage through the furnace jacket.

When operating the furnace under pressure more attention is required. The valves on the vacuum side are closed, the charge inserted, and the plug securely bolted in place. The compressor

can be run either continuously or intermittently as the experiment may demand, the object being to keep a higher pressure in the storage tank than in the furnace. The pressure in the furnace is controlled by means of the valve between the tank and the gauge, the gauge recording the pressure in the furnace. If for any reason the pressure in the tank is to be determined, the valve between the gauge and tank can be opened after first closing the valve between gauge and furnace. The reading now will be the tank pressure. The amount of gas passing through the furnace under any pressure is regulated by valves in the plug outlet at the opposite end of the furnace.

In certain observations it is convenient to operate the unit first as a vacuum, and then as a pressure furnace. For example, in determining the effect of a certain gas passing at a constant rate and temperature for a given time, evidently if the gas is started while the furnace is cold, the result obtained will show not only the effect produced at a certain temperature but also the effect produced in heating to and cooling from the desired temperature. This is obviated as follows. The furnace is exhausted when cold and then raised to the desired temperature. The gas desired is thus passed for the desired length of time, after which the furnace is again quickly exhausted and then allowed to cool. In this manner the effects produced in heating to and cooling from the working temperature can be almost completely annulled.

Experiments.

The following experiments (Series 1 to 12 inclusive) were conducted in the furnace which has just been described. The material subjected to carburisation was without exception "ingot iron" supplied by the American Rolling-Mill Company of Middletown, Ohio. It had the following chemical composition:

	Per Cent.
Carbon	0·01
Silicon	0·002
Sulphur	0·002
Phosphorus	0·003
Manganese	trace

The gases used were the city illuminating gas and acetylene.

The samples of iron to be cemented were turned down in a

precision lathe to a uniform diameter (within 0·001 of an inch) and were approximately 0·45 inch in diameter and 0·85 inch in length. Every sample was accurately weighed and measured before and after treatment. In all cases where oxidation did not occur, the change in weight was a sufficiently accurate measure of the carburisation ensuing. For purposes of comparison this change of weight was divided by the area of the specimen, introducing a column in the data tables, "change of weight per square centimetre of surface."

Series 1.—The conditions were as follows. City gas was passed at different rates and for different times at atmospheric pressure, the temperature being approximately 1000° in all cases. The conditions and results are shown in Table I. (p. 138). The conclusive result from this series was that city gas under the conditions of experiment did not carburise. An examination of the furnace tube showed that carbon was being deposited but not in the hot portion of the tube.

Series 2.—Series 2 was carried out as Series 1, except that the temperature was reduced to 900° C. The data for this series, Table II. (p. 139), gave results similar to Series 1.

Illuminating gas is unfortunately a mixture of several systems, but some general chemical laws are applicable. All systems in which carbon is deposited follow the general law that the higher the temperature (within limits) the greater the amount of carbon in the gaseous phase. The following system is typical. $2CO \rightleftarrows CO_2 + C$. At 500° C. about one-half of a given volume of CO would be dissociated into CO_2 and C, while at 1000° C. only 0·3 per cent. would be dissociated. In passing a given volume of CO through a tube held at 1000° C. the following must occur. The cold gas enters the tube and becomes heated gradually. As soon as the reaction temperature is reached carbon will be deposited and will continue to deposit until equilibrium is reached for the temperature in question. The gas, however, is never permitted to reach equilibrium, as it is constantly changing temperature. If the rate of flow is not too rapid the gas will reach the hot zone impoverished in carbon, and to again reach equilibrium must absorb carbon from some source.

Series 3.—After an inspection of the results of the previous series the first inference would be that the gases in the hot portion

TABLE I.—*Series* 1. *Cementation in Illuminating Gas.*

Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Temperature.	Pressure.	Rate of Gas Flow.	Hyper Case.	Eutectoid Case.	Hypo Case.	Total.	Remarks.
S-1-3	21·0803	0·0025	0·000227	3½	1020	Atmospheric	6 litres per hour	0	0	0	0	Specimen slightly blue. No case.
S-1-4	19·7149	0·0023	0·00022	3½	1020	,,	,,	0	0	0	0	,, ,,
S-1-5	20·6930	0·0005	0·000045	5	1000	,,	2 litres per hour	0	0	0	0	Blue on side facing current. No case.
S-1-6	18·5155	−0·0001	−0·00001	5	1000	,,	,,	0	0	0	0	Very bright. No case.
S-1-7	20·5942	0·0004	0·000036	4	1010	,,	0·0 litre. No gas passed	0	0	0	0	Slightly straw coloured. No case.
S-1-8	18·5018	0·0001	0·00001	4	1010	,,	,,	0	0	0	0	,, ,,
S-I-N-M	18·6430	0·0016	0·00016	3	1000	,,	3 litres per hour	0	0	0	0	Blued. No case.

TABLE II.—*Series 2. Cementation in Illuminating Gas.*

Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Temperature.	Pressure.	Rate of Gas Flow.	Hyper Case.	Eutectoid Case.	Hypo Case.	Total.	Remarks.
S-2-1	21·7640	−0·0002	−0·000018	6	900	Atmospheric	2 litres per hour	0	0	0	0	One side was light straw. No case.
S-2-2	19·9070	−0·0001	−0·000010	6	900	,,	,,	0	0	0	0	Very bright. No case.
S-2-3	22·4146	0·0003	0·000026	5	910	,,	0·2 litre per hour	0	0	0	0	Very light blue. No case.
S-2-4	22·1366	0·0000	0·00000	5	910	,,	,,	0	0	0	0	Light straw. No case.

The results are similar to those of Series I. In no case did carburisation ensue. Carbon was deposited in the cold ends of the tube as in the previous series.

TABLE III.—*Series 4. Cementation of Armco Iron in* C_2H_2.

Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Temperature.	Pressure.	Rate of Gas Flow.	Hyper Case.	Eutectoid Case	Hypo Case.	Total.	Remarks.
S-4-A	18·8181	0·0013	0·00013	4	1005	Atmospheric	1·44 litre per hour	0	0	0	0	Specimens dull black when removed. No trace of deposited carbon.
S-4-B	19·2017	0·0021	0·0002	4	1005	,,	2·75 litres per hour	0	0	trace	trace	,, ,,
S-4-C	19·2371	0·023	0·0023	4	1000	,,	10 litres per hour	0	0	3·5 mm.	3·5 mm.	Rear of tube choked. Specimen black. Case about 0·30 per cent. carbon.
S-4-D	19·3816	0·0578	0·0055	4	940	,,	·5 litres per hour	0	0·5 mm.	1·3 mm.	1·8 mm.	Furnace choked. Specimen black. Good commercial case.

of the tube would be decarburising. Carbon had been deposited from the gas mixture at lower temperatures to establish equilibrium, and as the temperature of the gas is raised carbon must again be absorbed to maintain the equilibrium condition. The only available carbon present in the hot zone is that of the austenite of the samples present which will be absorbed.

A great many experiments were carried out on decarburisation, only one of which will be described.

A strip of white cast iron 1 inch by $\frac{1}{4}$ inch by 6 inches was treated at 1025° C. for ten hours, city gas being passed at the rate of 6 litres per hour. The white cast iron used in these experiments was furnished by the International Harvester Company and contained 2·5 per cent. and 1·1 per cent. silicon.

Micrographs Nos. 1 and 2 (Plate I.) show the bar before and after treatment. The carbon in the flat bar of white cast iron has been reduced from 2·5 per cent. to about 0·50 per cent. The structure reveals streamers of ferrite extending to the centre of the strip. This structure has been observed several times in decarburised specimens but has not yet been accounted for. This strip was bent 45° before fracture occurred.

The other experiments on decarburisation with steels of varying carbon content showed the loss of weight per square centimetre of surface exposed, to be a direct function of the carbon content. In all cases the decarburisation was not accompanied by any oxidation, the specimens all remaining very brilliant.

Series 4.—Following the failure of illuminating gas to carburise C_2H_2 was next tried. The conditions were maintained as in all the previous experiments. The temperature used was 1000° C., the time constant four hours, and the rate of flow varied from 1·44 litre per hour to 10 litres per hour. The conditions and results for this series of experiments are summarised in Table III. (p. 139). The results show that no carburisation will result without a velocity of gas flow greater than 2·75 litres per hour. This condition is explained in a similar manner to the phenomena observed in Series 1 and 2. The decomposition of C_2H_2 is a complex reaction and several products may be formed :

$$2C_2H_2 = C_3 + CH_4$$
$$2C_2H_2 = C_2 + C_2H_2 \text{ etc.}$$

C_2H_2 is more stable at 1000° than at 400° or 500°, and as a result carbon is deposited in great abundance in the cold end of the tube, and when the hot portion of the tube is reached the gas lacks the necessary carbon to be in equilibrium. At all rates sufficiently slow the above condition results and no carburisation occurs, but increasing the rate to 10 litres per hour does not allow sufficient time for the complete deposition of the carbon in the cold end of the tube. Consequently the gas arrives in the hot zone still rich in carbon, which is given up to the iron forming austenite.

In order to study carburisation under equilibrium conditions, the following plan was used. The tube in which the specimens were treated was filled with solid carbon for about one-half its length. In this manner the gas was kept in equilibrium with solid carbon at the temperature desired to be used. The sketch on p. 142, Fig. 2, represents the tube as used in all the following series. The gas enters at the end of the tube, deposits carbon, and passes on. As it reaches the hot zone and is in the condition to absorb carbon it is at liberty to do so from the carbon packing. Carbon passes from the solid state into combination with the gas, the result being equilibrium between the gaseous phase and solid carbon at the temperature at which it is desired to effect carburisation. The gaseous phase passes on and strikes the specimens, to which it yields part of its carbon, causing cementation to ensue. It was impossible to work with C_2H_2 under pressure, and consequently the portion of the work in which C_2H_2 was used was confined to determining the degree of carburisation under different rates of flow and at different temperatures.

Series 5, 6, *and* 7.—The following experiments were confined to this work. The results shown in Tables IV. and V. (p. 144), and Table VI. (p. 147), are shown assembled in the form of a curve by a series of isothermals. (See Fig. 3.)

From this curve it appears that the extent of carburisation is a direct function of the rate of flow, and all the isothermals, except the one at 985°, can be drawn as straight lines. If a line AB is drawn parallel to the y axis intersecting this series of isothermals, the points of intersection furnish further information. Evidently at all points on this line the rate of flow is constant, which enables a curve to be drawn between temperatures and degrees of car-

burisation as the variables. This curve (Fig. 4) has a decided break in the region 890° to 900°. The interpretation of this break

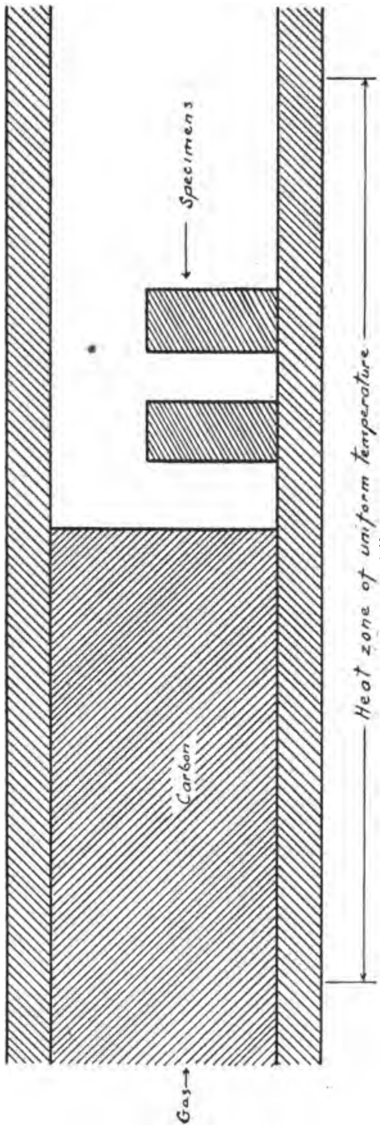


FIG. 2.—Arrangement of Furnace Tube with Specimens.

is that for a constant rate of flow, carburisation suddenly increases if the temperature is raised from 890° to 900°.

The region 890° to 900° is the location of the gamma-beta allotropic change in pure iron. The break in the curve is a very effective demonstration of the increased solubility of carbon in gamma iron, and in the author's opinion, shows beyond a reasonable doubt the possible solubility of carbon in beta iron.

A micrograph of this series is shown (No. 3, Plate II.). Some

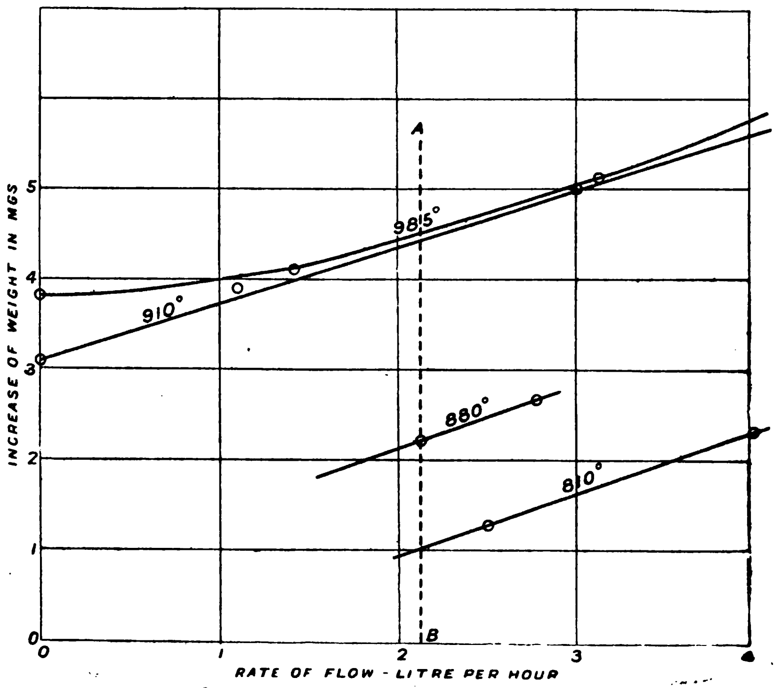


FIG. 3.—Series 5, 6, 7. Rate of Flow—Carburisation Curves.

have been insistent on the point that hydrocarbons give cases high in free cementite. This section shows quite the reverse. as in no instance do the cases exceed the eutectoid ratio.

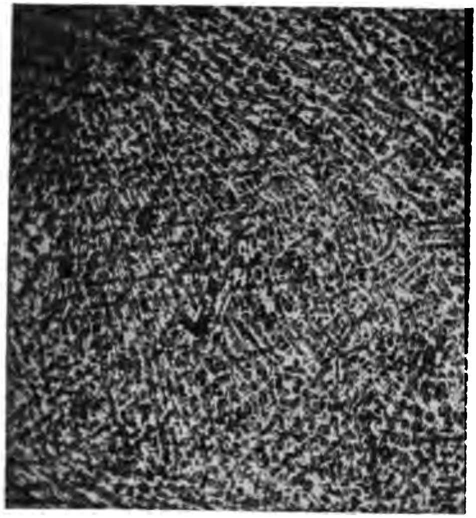
Series 8 *and* 9.—In the next series of experiments, illuminating gas was used as the carburising agent, the tube being filled for one-half its length with solid carbon, as explained before. All the specimens after treatment were perfectly bright and without a trace of oxidation. This condition made it possible to use the

TABLE IV.—*Series* 5. *Cementation in* C_2H_2.

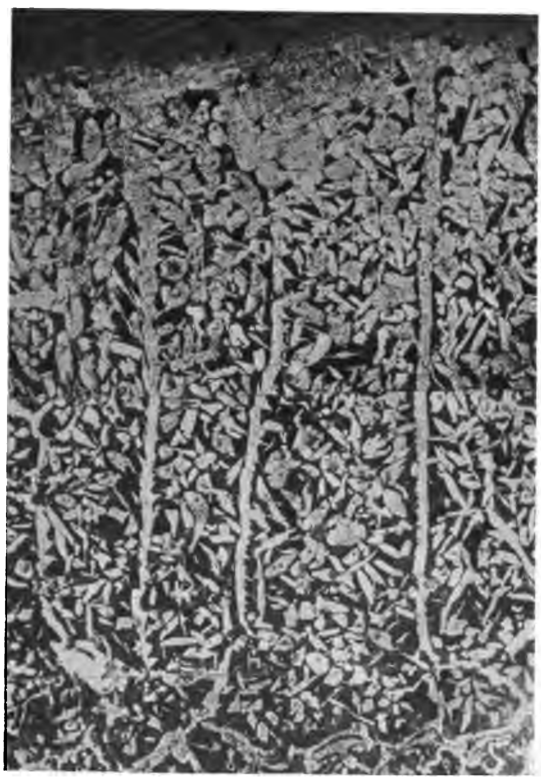
Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Tempera-ture.	Pressure.	Rate of Gas Flow.	Hyper Case.	Eutectoid Case.	Hypo Case.	Total Case.	Remarks.
S-5-G	19·3739	0·0431	0·0038	4	980	Atmos-pheric	0·00 litre per hour	0	0	1·25 m.	1·25 mm.	Carbon about 0·70 per cent. max. Specimen very bright.
S-5-E	19·3149	0·0431	0·041	4	985	,,	1·4 litre per hour	0	0	1·50 m.	1·50 mm.	Carbon about 0·70 per cent. max. Specimen very bright.
S-5-F	19·2207	0·0548	0·0052	4	985	,,	3·25 litres per hour	0	0·25 m.	1·50 m.	1·75 mm.	Specimen very bright.

TABLE V.—*Series* 6. *Cementation in* C_2H_2.

Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Tempera-ture.	Pressure.	Rate of Gas Flow.	Hyper Case.	Eutectoid Case.	Hypo Case.	Total Case.	Remarks.
S-6-I	19·2594	0·0326	0·0031	4	900	Atmos-pheric	0	0	0	1·4 m.	1·4 m.	0·75 metres about 70 per cent. carbon. Specimen very bright.
S-6-J	19·0167	0·0408	0·0039	4	905	,,	1·1 litre per hour	0	0	1·4 m.	1·4 m.	0·75 metres about 70 per cent. carbon. Specimen very bright.
S-6-K	19·2900	0·0527	0·0050	4	900	,,	3 litres	0	0·5 mm.	1·25 m.	1·75 m.	Specimen very bright.
S-6-H	19·2133	0·0229	0·0022	4	880	,,	2·25 litres per hour	0	0	1·1 m.	2·1 m.	,, ,,



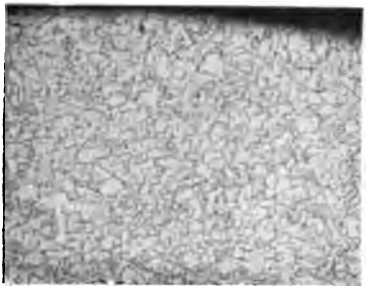
No. 1.—White Cast Iron, as received.



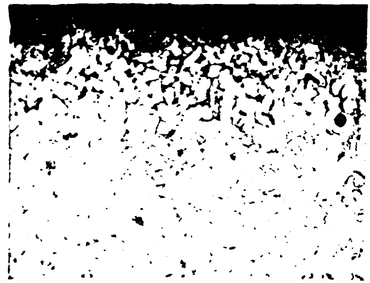
No. 2.—White Cast Iron, after decarburization.

To face p. 144.

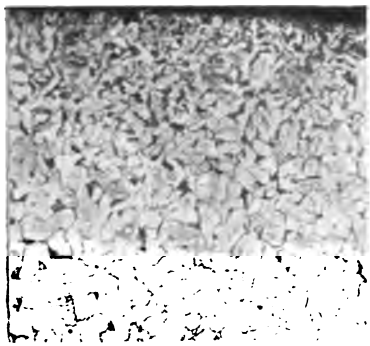
No. 3.—Armco Iron Carburized 4 hours in C_2H_2 at 1000° C.



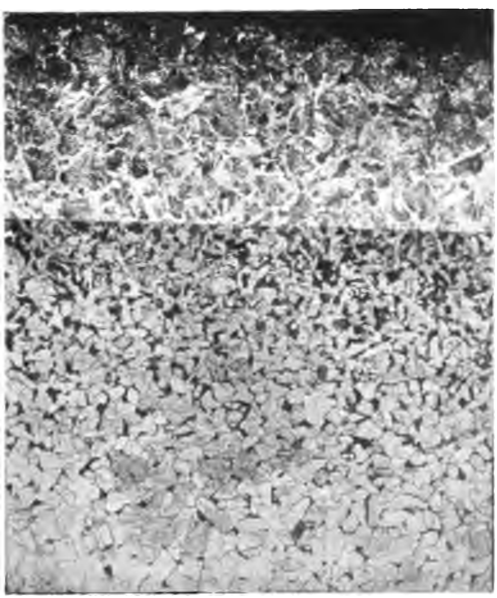
No. 4.—720° C.



No. 5.—810° C.



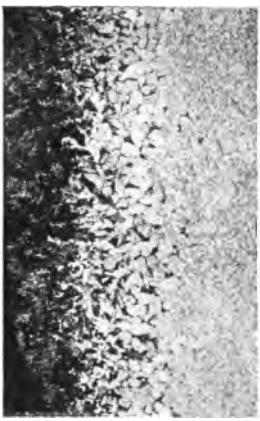
No. 6.—910° C.



No. 7.—1020° C.

Nos. 4–7 show depth of carburization of Armco Iron in illuminating gas at temperatures from 720° to 1020° C. at atmospheric pressure.

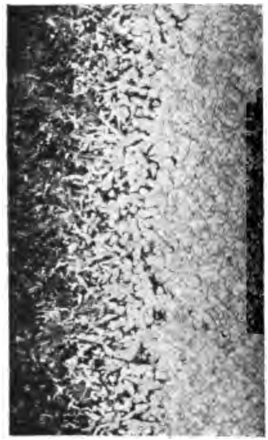
No. 8.—810° C. = 15 lbs.



No. 9.—810° C. = 40 lbs.

No. 10.—810° = 65 lbs.

No. 11.—805° C. = 90 lbs.



No. 12.—810° C. = 115 lbs.

Showing depth of carburization of Armco Iron exposed to Illuminating Gas at 800–810° C. under different pressures.

To face p. 145.

increase of weight as a direct measure of the carbon absorbed and also allowed of accurate measurements of the case depth.

As is shown in Table VII. the rate and time were constant, the temperature being the only variable. Two curves (Fig. 5) have been drawn from the data obtained, one showing the relation

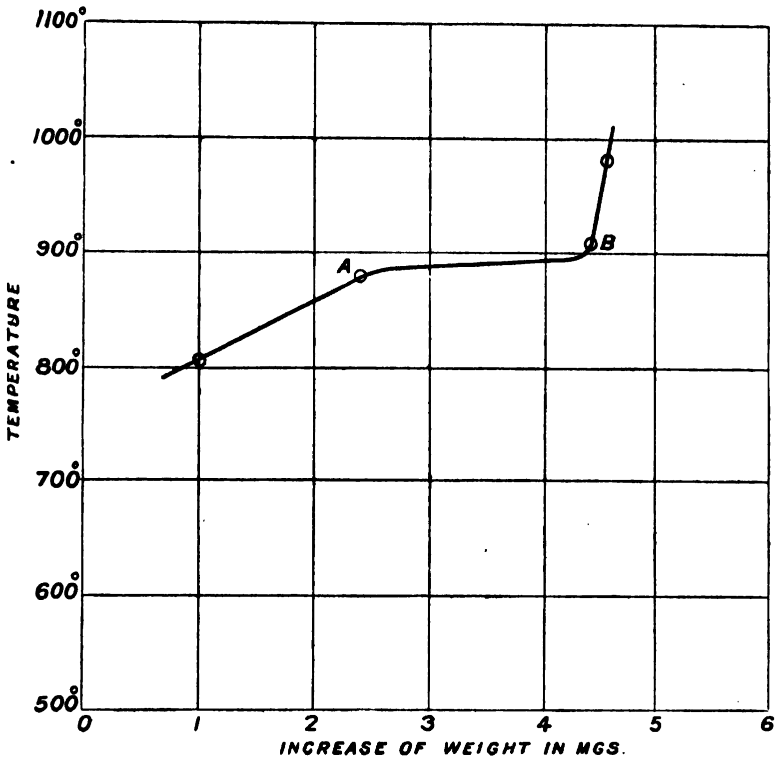


FIG. 4.—Temperature-Carburisation Curve. Data derived from previous Curve.

between temperature and increase of weight, the other showing the relation between temperature and depth of penetration of carbon. Micrographs Nos. 4 to 7, inclusive, show very clearly the increase of carbon absorption with temperature.

Both the curves in Fig. 5 show a change of slope in the region of 910°, which, interpreted in terms of solubility, must imply a less solubility in beta iron existing below 910° than in gamma iron existing above 910°. At some point between 725° and 810° the

process of carburisation no longer takes place. Although no point has been determined between 725° and 810°, it is not unreasonable to suppose that the change from the beta to the alpha state has some influence on this phenomenon.

Series 10.—The temperature of this series was 910°, which was maintained constant, as were all other conditions excepting pressure which was the variable. See Table VIII. (p. 148).

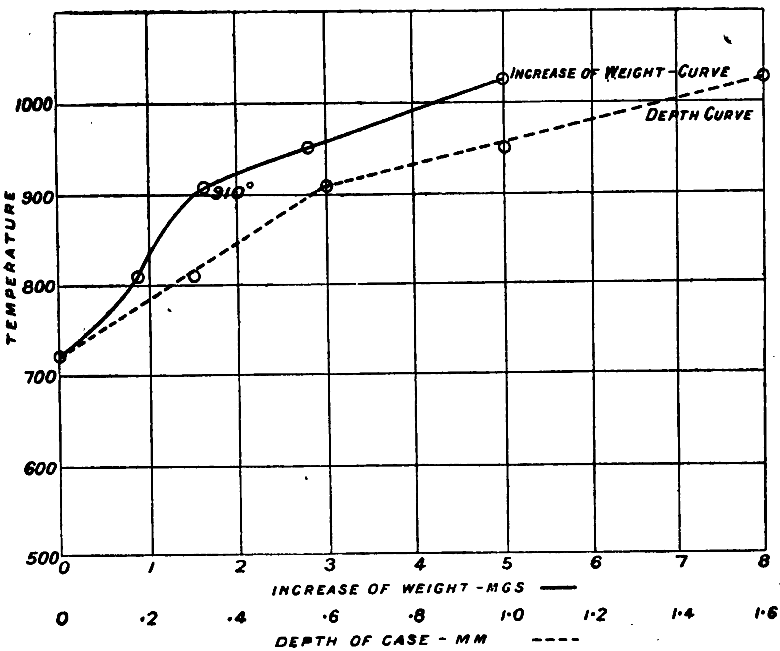


FIG. 5.—Series 9. Temperature-Carburisation Curve.

The curves shown in Fig. 6 never become parallel to the axis but approach parallelism at 115 lb. The increase of weight curve requires no explanation. Pressure increases the absorption of carbon, rapidly as the pressure is first increased. Afterwards at higher pressures increments of pressure seem to have but little effect on the amount of carbon absorbed.

The depth of case curve, Fig. 8, has been plotted in two branches which in reality are two curves overlapped to the point A. Curve OAB is the total depth of case curve. Curve OAC is the curve

TABLE VI.—*Series 7. Cementation in* C_2H_2

Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Tempera-ture.	Pressure.	Rate of Gas Flow.	Hyper Case.	Eutectoid Case.	Hypo Case.	Total Case.	Remarks.
S-7-L	19·5552	0·0265	0·0025	4	810	Atmos-pheric	4 litres	0	0	1 mm.	1 mm.	Specimen very bright. Case low in carbon.
S-7-M	19·3124	0·0641	0·0061	4	900 Uncertain	,,	1·6 litre	0	0·4 mm.	1·1 mm.	1·5 mm.	Specimen very bright.
S-7-N	19·3624	0·0646	0·0061	6	900 Uncertain	,,	0	0	0	2 mm.	2 mm.	Specimen very bright. 0·6 millimetre about 0·60 per cent. carbon
S-7-0	19·3789	0·0278	0·0027	4	880	,,	2·75 litres	0	0	1 mm.	1 mm.	Specimen very bright.
S-7-P	19·4602	0·0133	0·0013	4	815	,,	2·50 litres	0	0	0·8 mm.	0·8 mm	,, ,,

TABLE VII.—*Series 9. Illuminating Gas.*

Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Tempera-ture.	Pressure.	Rate of Gas Flow.	Hyper Case.	Eutectoid Case.	Hypo Case.	Total Case.	Remarks.
S-9-S	19·2463	−0·0006	−0·00005	3	720	Atmos-pheric	5 litres per hour	0	0	0	0	Specimen very bright.
S-9-P	19·3796	0·0089	0·0009	3	810	,,	,,	0	0	0·3 mm.	0·3 mm.	,, ,,
S-9-Q	19·4453	0·0171	0·0016	3	910	,,	,,	0	0	0·6 mm.	0·6 mm.	,, ,,
S-9-O	19·3815	0·0298	0·0028	3	950	,,	,,	0	0	1·0 mm.	1·0 mm	,, ,,
S-9-R	19·4783	0·0522	0·0050	3	1025	,,	,,	0	0·25 mm.	1·35 mm	1·6 mm	,, ,,

TABLE VIII.—*Series* 10. *Illuminating Gas.*

Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Temperature.	Pressure. Lbs.	Rate of Gas Flow.	Hyper Case.	Euctectoid Case.	Hypo Case.	Total Case.	Remarks.
S–10–F	19·3041	0·0476	0·0046	3	910	25	5 litres per hour	0	0·25 mm.	0·75 mm.	1·0 mm.	Specimen very bright.
S–10–E	19·3406	0·0476	0·0045	3	915	33	,,	0	0·25 mm.	0·75 mm.	1·0 mm.	,, ,,
Sp–4	19·4369	0·0559	0·0053	3	915	45	,,	0·2 mm.	0·25 mm.	0·65 mm.	1·1 mm.	,, ,,
S–10–B	19·3367	0·0690	0·0066	3	915	65	,,	0·3 mm.	0·3 mm.	0·65 mm.	1·25 mm.	,, ,,
S–10–C	19·3240	0·0740	0·0071	3	915	90	,,	0·4 mm.	0·25 mm.	0·65 mm.	1·30 mm.	,, ,,
S–10–D	19·3978	0·0787	0·0075	3	915	115	,,	0·45 mm.	0·25 mm.	0·7 mm.	1·40 mm.	,, ,,
S–10–V	19·4486	0·0700	0·0067	3	925	32	,,	0·5 mm.	0·3 mm.	1·0 mm.	1·80 mm.	Temperature control bad. Too high for series.
S–10–A	19·4885	0·0359	0·0034	2	915	45	,,	0	0·2 mm.	0·8 mm.	1·00 mm.	Fuse blown. Sp. 4 run to replace same.
S–10–W	19·5324	0·0976	0·0093	3	950 to 1000	45	,,	0·6 mm.	0·25 mm.	1·00 mm.	1·85 mm.	Temperature control bad. Too high for this series.

in which the ordinates are the thickness of the eutectoid and hypo-eutectoid layers. The region BAC is a hyper-eutectoid zone. From these two curves the conclusion is evident that any increase of thickness of case caused by raising the pressure above

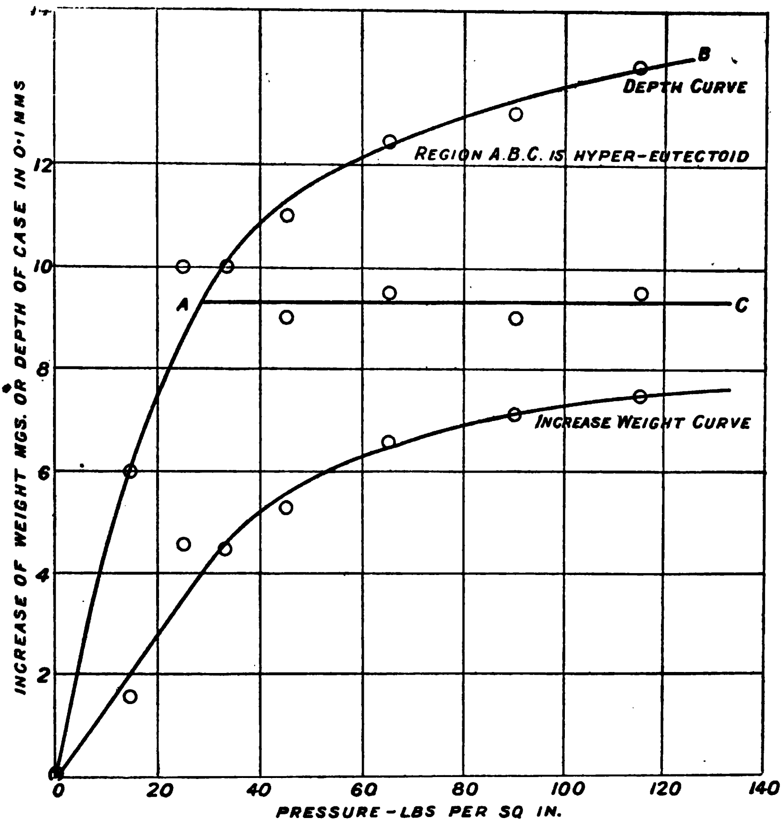


FIG. 6.—Series 10. 910° C. Pressure-Carburisation Curve.

25 lb. is due to an increase of the hyper-eutectoid shell and not to an increase of the lower carbon content portions of the case.

Series 11.—This series was conducted at 800°. From the data in Table IX. two curves, Fig. 7, have been drawn, one showing the relation between change of weight and pressure, the other between thickness of case and pressure.

The first conclusion which can be drawn is that pressure

increases the carbon absorbed up to a certain limit. Increasing the pressure beyond 40 lb. causes no further increase in the amount of carbon absorbed, the time and temperature remaining constant. The temperature of this series, as before stated, was in the vicinity of 800°. For every temperature the curve becomes parallel to the axes at a different pressure; the higher the temperature, the higher the pressure must be to produce this effect.

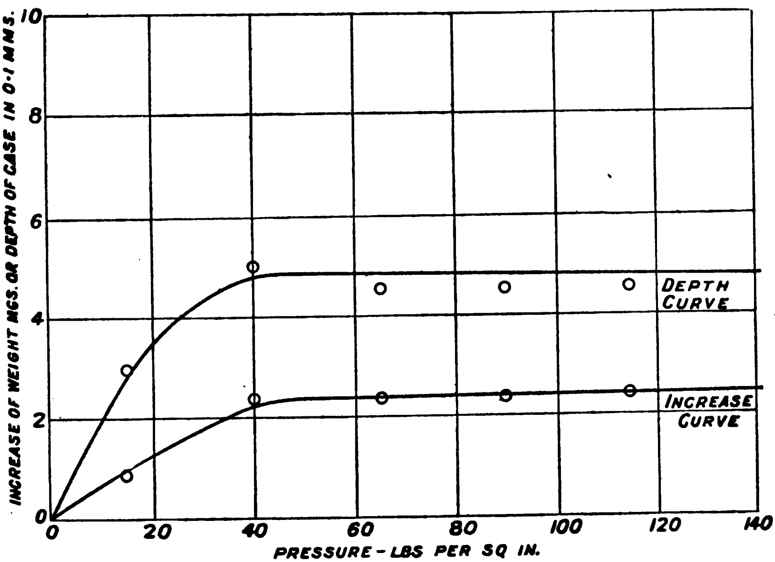


FIG. 7.—Series 11. 810° C. Pressure-Carburisation Curves.

Micrographs Nos. 8 to 12, inclusive, show the typical cases resulting from this series.

Series 12.—This series, which was conducted at 995°, was limited at a maximum pressure of 75 lb. The curves, Fig. 8, have been drawn as in the previous series. The curve for the increase of weight shows a tendency to flatten as in Series 10 and 11. In Fig. 9 the increase of weight curves have been assembled and permit of the general statement that increase of pressure increases the absorption of carbon at all the temperatures studied. After a certain critical pressure is reached, the critical pressure depending on the temperature, increments of pressure cause no further increase in carburisation. The data for experiment 12 are shown in Table X. and Fig. 8.

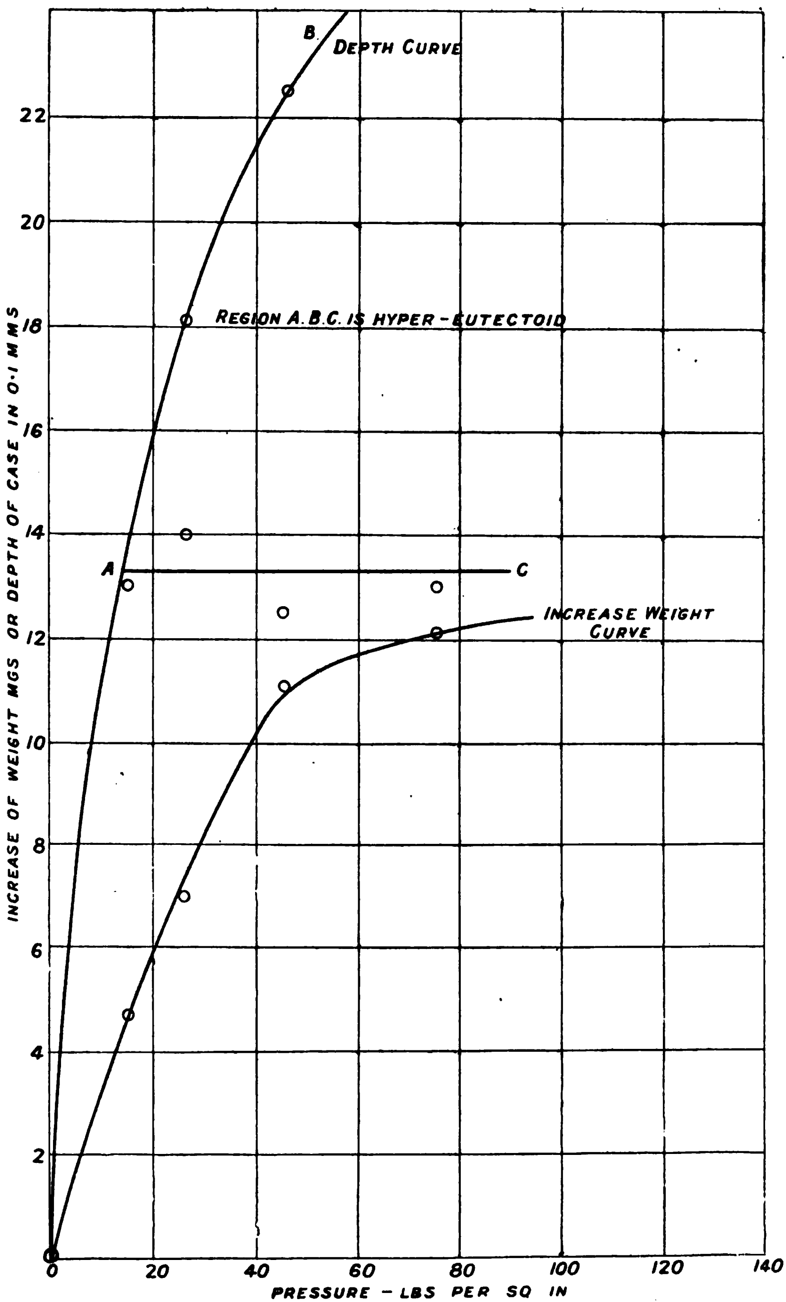


FIG. 8.—Series 12. 990° C. Pressure-Carburisation Curve.

TABLE IX—*Series* 11. *Illuminating Gas.*

Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Temperature.	Pressure. Lb.	Rate of Gas Flow.	Hyper Case.	Eutectoid Case.	Hypo Case.	Total Case.	Remarks.
S-11-G	19·4964	0·0247	0·0024	3	810	40	5 litres per hour	0	0·2 mm.	0·3 mm.	0·5 mm.	Specimen very bright.
S-11-H	19·3985	0·0245	0·0023	3	805	65	,,	0	0·2 mm.	0·3 mm.	0·45 mm.	,, ,,
S-11-I	19·4796	0·0244	0·0023	3	805	90	,,	0	0·2 mm.	0·3 mm.	0·45 mm.	Specimen very bright. Grain growth.
S-11-J	19·2400	0·0253	0·0024	3	810	115	,,	0	0·2 mm.	0·3 mm.	0·45 mm.	Specimen very bright. Grain growth.

TABLE X.—*Series* 12. *Illuminating Gas.*

Specimen.	Weight in Grammes.	Change of Weight.	Change per Sq. Cm.	Time. Hours.	Temperature.	Pressure. Lbs.	Rate of Gas Flow.	Hyper Case.	Eutectoid Case.	Hypo Case.	Total Case.	Remarks.
S-12-L	19·1488	0·0741	0·0070	3	990	26	5 litres	0·4 mm.	0·5 mm.	0·9 mm.	1·8 mm.	Specimen very bright.
S-12-M	19 3073	0·1109	0·0105	3	990	45	,,	1·0 mm.	0·5 mm.	0·75 mm.	2·25 mm.	,, ,,
S-12-N	19·5081	0·1207	0·0120	3	995	75	,,	1·3 mm.	0·5 mm.	0·8 mm.	2·6 mm.	,, ,,
S-12-K	19·1081	0·0493	0·0047	6½	800	27	,,	0·2 mm.	0·3 mm.	0·5 mm.	1·0 mm.	Voltage low, could not get 990, 800 max. Control bad.

SUMMARY.

1. The furnace herein described has proved very convenient and simple of operation.

2. Experiments on carburisation and decarburisation were carried out, using both illuminating gas and acetylene.

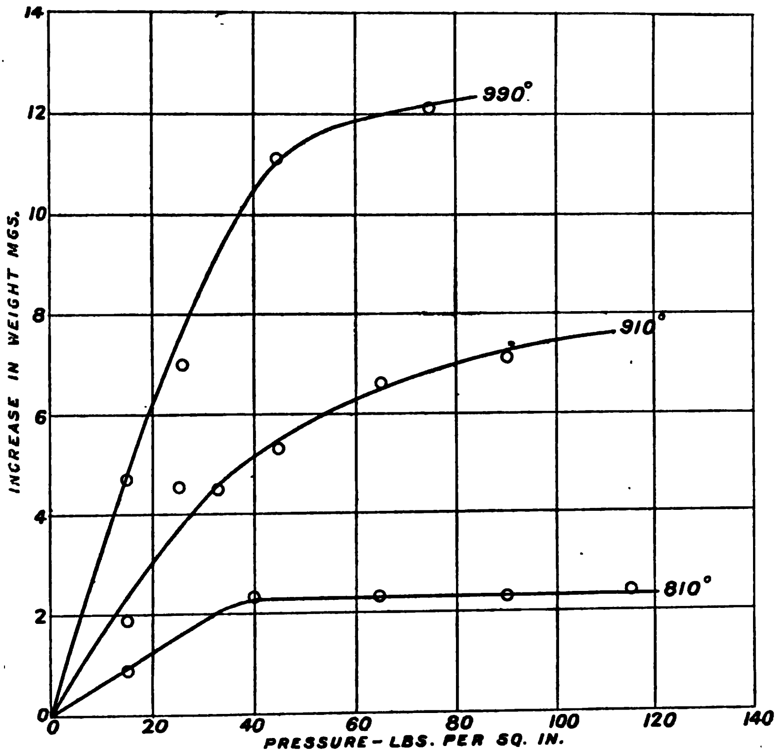


FIG. 9.—Series 10, 11, 12. Increase of Weight. Pressure Curves for 810°, 910°, 990°.

3. The gamma-beta points seem to mark a sharp break in the carburisation curves for both city gas and acetylene. No carburisation ensued below 720°.

4. The effect of pressure on the degree of carburisation with the gaseous systems found in illuminating gas was different at different temperatures. It is indicated by the various curves that after a certain pressure is reached further increase of pressure will not cause additional absorption of carbon by the iron.

THE INFLUENCE OF SURFACE TENSION UPON THE PROPERTIES OF METALS, ESPECIALLY OF IRON AND STEEL.

By F. C. THOMPSON, D.Met., B.Sc. (Sheffield).

In an earlier paper[1] an attempt was made to correlate the properties of metals, and in particular the elastic limit, with the effect of the surface tension which was supposed to act at the crystal boundaries. In view of the importance of the subject, and of the fundamental nature of some of the criticisms levelled against this hypothesis, it becomes necessary to consolidate the position there taken, and to deal more fully than could well be done in the discussion with the questions which were raised. As a result of present abnormal conditions no new experimental work has been carried out for the present contribution, although there are several directions in which this is required before full credence can be placed in the hypothesis tentatively proposed.

To the author the evidence available that surface tension can, and does, make its influence felt in defining the structure, and hence the properties of metals and alloys, appeared so overwhelmingly great that it was taken more or less for granted in the first paper. Since, however, no less an authority than Dr. Rosenhain was unable to believe that a surface tension of any appreciable magnitude could be expected between the crystalline phase and the intercrystalline amorphous modification, the author has in the present contribution reviewed the available evidence more fully, and extended it in several interesting directions.

The other main criticism of Dr. Rosenhain may perhaps be considered first, namely, that whether the surface tension hypothesis can be justified scientifically or not, it is unnecessary, the mere strength of the intercrystalline vitreous modification being sufficient to explain the whole of the phenomena.

So far as the explanation goes of the fact that fracture of

[1] F. C. Thompson, *Journal of the Iron and Steel Institute*, 1916, No. I. p. 155.

a normal metal sedulously avoids the crystalline boundaries, passing by preference through the mass of the crystalline grains, such a simple hypothesis may be sufficient. Immediately, however, this idea is used to explain more or less quantitatively the remarkable increase of elastic limit and of tensile strength imparted to a metal by an increase of the crystal boundaries, *i.e.* by refining the grain, so soon does it lead to results of an order in the highest degree difficult of acceptance. A single instance may be taken from the results previously recorded, which, however, is in full agreement with the results of general experience.

The maximum stress of the sample of iron containing 0·049 per cent. carbon was in the annealed condition: 21·1 tons per square inch, and after normalising 21·8 tons. The small amount of Fe_3C being of the same amount and similarly distributed in each sample, the alteration of tensile strength must be attributed to the change in the crystalline size from 700 crystals per inch in the annealed state to 870 in the normalised. Now considering for simplicity the crystals to be squares in cross section, and the thickness of the films to be the mean of those of the iron and steel samples already calculated, *i.e.* $1{\cdot}5 \times 10^{-6}$ centimetres,[1] the difference in the area of the cement in inch square test-bars of the two samples would be $2(870\text{–}700) \times 1{\cdot}5 \times 10^{-6} \times 2{\cdot}54$ square inches, *i.e.* about $1{\cdot}28 \times 10^{-3}$ square inches, which area, if the simple strength of the cement is to explain the increased maximum stress of the normal over the annealed sample of iron, has a strength of 0·7 ton. The cement must therefore be credited with a tensile strength of almost 550 tons per square inch. Since the corresponding value for crystalline iron is in the region of 20 tons per square inch this high value is improbable, and some other factor than the mere strength of the amorphous modification must be sought. If material of such properties existed at the boundaries it is to be expected that it would make its presence apparent as a raised cellular structure on a merely polished surface, as cementite often does when it occurs in this

[1] In connection with these results for the thickness of the amorphous films it is in the highest degree remarkable that they are in most excellent agreement with Sir George Beilby's own estimate, who in a private communication to Professor Howe ("Metallography of Steel and Cast Iron," p. 374) gives the probable thickness of amorphous films produced by cleavage slipping as 20 to 30 $\mu\mu$, *i.e.* 2 to 3×10^{-6} centimetres. Although the films so produced are not in all respects identical with those around the crystals, the fact that the thickness deduced as a result of the surface tension theory of the elastic limit should be in such very close correspondence is strong evidence in favour of its truth.

form. Further, a Turner sclerometer scratch fails to change its width on crossing the grain boundaries, which would certainly be expected, however thin the films might be, if they were possessed of such high tenacities as they would act as a breakwater, strengthening the soft material in their immediate neighbourhood. Surface tension supplies at once a plausible and, so far as the author can see, almost the only possible alternative to this simpler but insufficient view, that all that is required is that the intercrystalline films should be "stronger per unit of area than the crystalline material."

This is, however, by no means all. It is not quite easy to see why the mere existence of a hard modification between the crystals should cause the latter to adhere at all. At any rate it affords no obvious explanation why the boundaries become the strongest part of the mass. The most that can be expected if two surfaces of a material are to be kept in contact by simple adhesion is that the union should be nearly as strong as the cohesion of the material itself. It is unthinkable that under such conditions the masses should be brought together so closely as to adhere more strongly than do the molecules lying on adjacent cleavage planes. There is further no reason to believe that the mere introduction between the crystals of another and harder material would increase the strength of the attraction of these crystals for each other, in fact direct experimental evidence is available in opposition to such a view. Bismuth is distinctly harder than pure gold, and yet the introduction to the latter of a trace of the former, practically the whole of which is found between the crystals of gold, renders the intercrystalline strength almost non-existent, the alloy being intensely brittle, devoid of ductility, and breaking with an intergranular fracture.

We are therefore again forced to the conclusion that the hypothesis of a hard intercrystalline cement is not sufficient to explain by any means all the phenomena which must be taken into account, and that a consideration of the possibilities of the surface tension hypothesis of intercrystalline strength is by no means unnecessary.

In much the same direction lies the weakness of Professor Howe's criticism, and of his attempt to explain the remarkable strength of the crystal boundaries simply by the change in

direction of the gliding planes upon which slip occurs on passing from one crystal to the next. Such a view-point is sufficient to explain several important facts, as, for instance, the increased resistance of the metal to the commencement of plastic deformation as the crystals become smaller, a fact which was brought out in the author's previous paper, where it was shown that empirically the elastic limit is proportional to $n^{\frac{1}{2}}\mathrm{T}$ where n is the number of crystals per unit length. Some defects of this hypothesis of Professor Howe's, however, lie firstly in the fact that again no explanation whatever is given as to why the crystals do not fall apart under even the smallest stress, and secondly in the failure to account for the perfectly definite dependence of the elastic limit of the metal upon its surface tension, a relationship abundantly shown in the curve (Fig. 3) and in the results in Table III. of the earlier paper. The curve alone appears to the author to demonstrate beyond doubt the fact that the surface tension of a material is one of the factors which determines its elastic limit, and an exceedingly important one at that.

In this connection, since it also satisfies Professor Howe's second criticism, we may perhaps consider very briefly the reason for the dependence of the elastic limit upon the size of the crystals, when theoretically:

$$\mathrm{E} = \frac{2\mathrm{T}}{d}$$

where E is the elastic limit,
T ,, surface tension,
and d ,, thickness of the amorphous films,

a formula which does not involve a function depending upon the crystalline size. As Professor Howe has pointed out, the cutting in two of a wooden bar, and the gluing together of the pieces again with an infinitely strong cement, does not increase its strength, since, when the piece is again broken, the fracture finds another path. The analogy appears, however, to be somewhat defective when a crystalline aggregate such as a normal metal is considered. A truer one would be a criss-cross scaffolding, when the increased strength which accompanies a smaller lattice is readily understood. Such a picture does offer a true comparison, since on all crystal boundaries, except those parallel to the direction of an impressed force, there is found a resolved part of the surface tension attraction equal to $\frac{2\mathrm{T}}{d}\cos\theta$, where θ is the angle between the boundary and the direction of the force. A tensile

strength therefore may be assumed in each of the members of the scaffold, and hence in the scaffolding itself, which latter will become stronger and stronger as the number of poles forming it increases.

In passing it may be worth while remarking that the surface tension hypothesis is not in any way, as Dr. Rosenhain has asserted, dependent upon the extension of Van der Waal's equation to the solid state. At no point whatever does this enter into the author's theory of the elastic limit.

Having thus seen that some such additional factor as surface tension is required in a presentation of an explanation of all the facts concerning the strength of aggregates of metallic crystals, we may proceed to a consideration of the objection raised that a surface tension of any magnitude cannot be expected between a crystal and the amorphous form of the same material, since the density of the two are almost the same. That difference of density is not the chief cause in determining the magnitude of an interfacial tension, is readily seen from the fact that at 20° C. the interface tension of water and olive oil, the density of which is 0·914, is 20·56, a quite high value for such substances as oil, despite a density difference of only 0·086.

There are, however, abundant proofs that a surface tension of quite a high order is found between the crystalline and amorphous modification of the same *pure* substance, and the following three examples chosen from several available ones may suffice.

Fig. 1 [1] (Plate V.) is a photograph of a dendrite of lead withdrawn from the residual liquor during solidification. That surface tension between this and the liquid metal at the same temperature has been at work is evidenced by the rounding off the angles. The conditions at the crystal boundaries in a solid metal are strictly analogous to those here obtaining, whence an appreciable surface tension is equally to be assumed. Tin and aluminium are other metals in which rounded dendrites are formed.

The second justification is supplied by a study of the liquid crystals. In many of these, as has been shown time after time, the external crystalline form is obliterated by surface tension forces, and a more or less spheroidal one is assumed. This occurs when the drops are suspended in the non-crystalline liquid of

[1] Gulliver, "Metallic Alloys," 2nd edition, p. 215, Fig. 154.

the same composition, temperature, state of aggregation, and closely identical density. Fig. 2 (Plate V.) shows such crystals of para-azoxyanisol. Le Chatelier [1] has drawn attention to the close analogy which exists between the growth of the crystals in a metal during annealing, and the coalescence under surface tension of liquid or plastic crystals, as a result of the common tendency to attain that state with the minimum surface energy.

Further confirmation may be drawn from an entirely different direction. As the state of division of a substance becomes finer, and the amount of surface increases, effects due to surface tension become more and more striking. Thus as Ostwald and Hulett have shown,[2] the solubility of a substance is dependent on the size of the particles, and the phenomenon has been used for measuring the surface tension of substances in the *solid* state. The values so determined for calcium and barium sulphates are 1100 and 4000 dynes per centimetre respectively, which are of great interest in showing the very high values of this constant in solids. For the solid metals, arguing from the very high value of the constant for liquid mercury compared with other liquids, the surface tension may be expected to be considerably higher still. It is, however, the effect of the surface tension of a solid upon the melting point which supplies the third proof of its effectiveness between the crystalline and non-crystalline forms of the same substance. It has been shown that granules of salol with a surface of 230–1300 μ^2 have a melting point 2·9° C. lower than particles with a surface 100 times greater, *i.e.* whose diameter is ten times as great, a lowering produced by surface energy between the crystalline and non-crystalline.

That the assumption of a surface tension in solid metals between the crystalline grains and the amorphous intercrystalline films is justifiable there can therefore be no doubt, nor is there reason to limit its value to a small magnitude. The criticism levelled against the surface tension theory of the elastic limit on that account, therefore, finds a completely satisfactory reply.

It now becomes of great interest to determine to what extent the application of the hypothesis to the more practical aspect

[1] Le Chatelier, *Revue de Métallurgie*, 1906, p. 105.
[2] Willows and Hatschek, "Surface Tension and Surface Energy," p. 24.

FIG. 1.

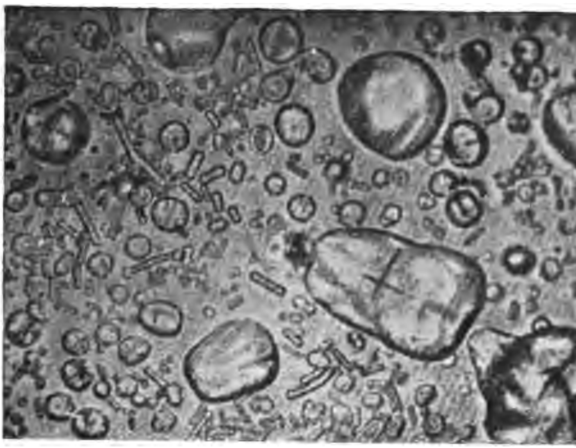


FIG. 2.

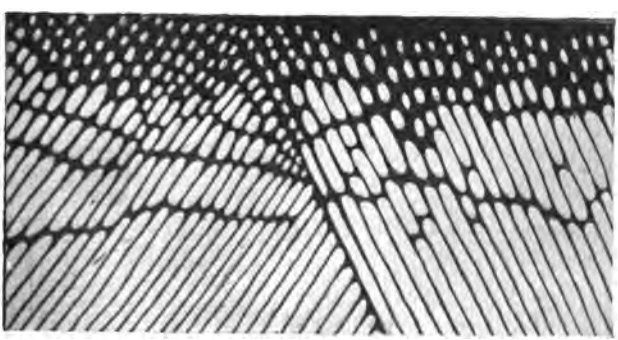


FIG. 3.

To face p. 160.

Reduced by one-fifth.

FIG. 6 —Magnified 500 diams.

FIG. 8.—Magnified 500 diams.

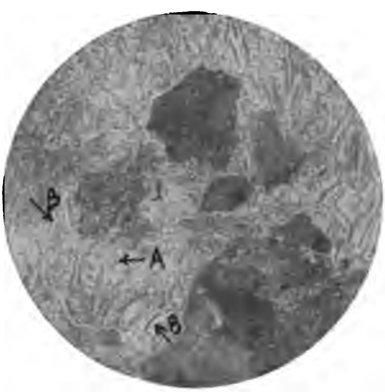


FIG. 7.—Magnified 500 diams.

A. Coalescence Cementite Globules under surface tension.
B. Break up of Fe_3C plates under surface tension.

FIG. 9.—Magnified 500 diams.

of metallography yields valuable results. The complex changes which practically pure iron undergoes on recrystallisation after cold work offer excellent scope for such an inquiry.

Work on this subject by Charpy, Le Chatelier, Sauveur and Chappell has resulted in elucidating the following facts. When iron is plastically deformed, by, for instance, pressure from a Brinell ball, though bending or other forms of stress yield corresponding results, and then annealed at temperatures from 650° C. to 870° C., a section cut through the centre of the depression reveals three well-defined zones. In that nearest to the surface, in which the stress attained its maximum intensity, and in that farthest away, where the elastic limit was not reached, or but little surpassed, the size of the crystals is more or less unaltered. Between these two areas, however, an exceedingly coarse crystallisation obtains, which is sharply localised where it comes against the least strained zone, but merges more gradually into the overstrained portion. This of course would not have been expected, it being reasonable to assume that any change induced by the deformation would be proportional to the distortion undergone.

Several explanations of the facts have been suggested, but since they are all, with the exception of that of Robin, insufficient or doubtful, they need not be considered here. The question is further complicated by the fact that, as shown by Chappell, recrystallisation actually commences in the surface zone of greatest stress before it does in the middle one, in which, therefore, the rate of growth must be very greatly accelerated once it has commenced.

Before proceeding to show that the application of the hypothesis of surface tension forces between a crystal and the surrounding vitreous modification is capable of reducing to order the whole series of results, it may be well briefly to recall a few fundamental facts regarding the action of such surface forces upon exceedingly small particles.

If a bubble of vapour of radius a is immersed in a liquid, the surface tension of which is T, the pressure within the bubble is greater than that outside by $\frac{2T}{a}$. For small values of a, *i.e.* for very small bubbles, this excess is very considerable, and on heating, the temperature must often be raised much

above the boiling point before expansion of the bubbles can occur and the liquid boil. When this does happen, it does so suddenly and with violence, or, as it is usually termed, the liquid "bumps." The introduction to the liquid of a porous material containing air, by providing air-bells already of considerable size, eliminates this period of quiescence and normal boiling ensues. The converse process, the formation of drops of mist from a supersaturated gas, is equally important. In a dust-free atmosphere a high degree of supersaturation is required to produce a mist on account of the great tendency to evaporation of very small drops, another example of surface tension. Where, however, dust nuclei are present on the comparatively large surfaces of which dew can be formed, the production of mist is an easier process. In both these examples, it is in the case of the smallest globules when boiling or condensation is on the point of initiation that the inhibitive effects are so obvious. Once this stage is passed both proceed along more nearly normal lines.

To apply these phenomena to the recrystallisation of ferrite plastically deformed, one assumption only need be made, which, moreover, is so reasonable that it may be regarded as almost axiomatic. It is assumed that the effect of severe distortion in the cold is to reduce the originally crystalline aggregate to a debris of small remains of crystalline matter embedded in a vitreous matrix. This of course is Beilby's view, and his diagram,[1] Fig. 3 (Plate V.), so exactly illustrates the condition that it is here reproduced.[2] A less severe deformation of the mass results in a localisation of the effects. There is no longer a uniform crushing, the disturbance occurring to the greatest extent in the neighbourhood of the planes upon which motion has occurred, while in between there exist islands of unchanged crystalline matter which grow as the strain becomes less and less until they constitute the whole mass. This increase in size necessitates of course a corresponding decrease in their number.

On reheating such a deformed material the tendency is for the crystal islands to grow again at the expense of the vitreous

[1] Beilby, *Philosophical Magazine*, 1904, August, p. 264.

[2] It should be borne in mind that these remarks apply only to the microscopically invisible internal structure. An ordinary microscopic examination of the etched surface still shows the original crystals elongated in the direction of the stress but otherwise unchanged. There is, however, little reason to doubt that internally the conditions shown in Beilby's diagram obtain.

portion. Now in exactly the same way that the liquid would not boil, *i.e.* that small bubbles could not form and grow, and that the condensation of small drops of dew did not form in the supersaturated dust-free air, so it is reasonable to assume that the forces of surface energy prevent the growth of the smallest islands in the most severely deformed metal. Thus Chappell[1] has shown that the disintegration of deformed ferrite crystals tends to occur at so low a temperature as 350° C., as shown by markings which occur in the crystal on etching, but not till 500° C. or over is reached is there a visible change in the external boundaries or in newly recrystallised areas within the original crystals. When, however, this new crystalline growth from the crushed matrix does commence it proceeds with really remarkable rapidity, and at 570° C. the crystal debris had disappeared, a complete recrystallisation having occurred, the new crystals henceforward growing steadily and normally up to the point Ac3.

Now it may at first sight appear to many a very far-fetched analogy to compare this process of recrystallisation of ferrite to the bumping of, for instance, sulphuric acid, but it is in reality exceedingly close, and since we have already seen that surface tension must be regarded as existing between the crystals in a metal, and since it is to a manifestation of surface energy that the irregular vaporisation of the bumping liquid is certainly to be ascribed, both in its cause and in its effect, the recrystallisation of deformed ferrite does appear to be a similar process. The curve, Fig. 21 of the paper quoted, illustrating this growth in Swedish wrought iron supplies admirable confirmation. Up to, in this case, about 665° C. no crystal growth has taken place, but then commencing, it becomes rapidly exceedingly active to about 800° C., when it becomes almost stationary again, the unstable condition having given place to the stable state. The curve exhibits the typical feature of the growth of bubbles in a liquid of suspended boiling which form first at a high temperature, growing then with almost explosive violence. As Chappell remarks regarding the crystalline growth in deformed ferrite, once this has been initiated, "another conspicuous feature of the growth of deformed ferrite crystals is the rapidity with which union takes place."

[1] *Journal of the Iron and Steel Institute*, 1914, No. I. p. 460.

Having thus seen that the hypothesis of surface tension between the crystals of a metal does afford an adequate explanation of the general conditions of crystalline growth when the plastically deformed mass is annealed, we may apply it further to explain the remarkable coarse structure produced as a result of reheating to 650°–900° C. after certain stresses. It has been abundantly proved that the recrystallisation of a cold-worked metal does not occur by a simultaneous recrystallisation throughout the mass, but by the growth of certain isolated grains specially favoured. Figs. 3, 4, and 7 of Chappell's paper illustrate this point well, though it is of general truth. A satisfactory explanation of the reason that certain nuclei receive a preferential treatment will afford the key to the complex phenomena now to be considered. We have already seen that one of the effects of surface tension in iron is to prevent the growth of very small crystals—since it is in these that its action is most powerful—until at any rate a temperature is reached much above that at which it would otherwise commence. Further, the size of the crystal islets influences the result appreciably. Just as the solubility of calcium and barium sulphates, *i.e.* the passage from crystalline to non-crystalline, increases as the particles become smaller, so does the tendency for *growth* of the ferrite remains *decrease* as they become smaller. It is, therefore, those ferrite particles of the greatest size which have survived the deformation which begin to grow again most rapidly when the minimum annealing temperature is reached. This has been realised for some time, but its essential dependence upon the forces of surface energy has not been so widely recognised.

Now reverting to the fine superficial, the coarse-grained intermediate, and the unaltered most distant zones of the annealed Brinelled sample of iron, the first has its crystalline islets all very small and of more or less the same size. Thus, in the first place, the inhibitive effect of surface tension on recrystallisation will be a maximum, while in addition the crystalline residues from which regrowth must start will be exceedingly small, very numerous, and of fairly constant size. The conditions, therefore, are all such as will result in a large number of small crystals on annealing. Passing on to regions less and less severely disturbed, islands will be retained which become gradually larger and larger,

though around them along cleavage planes the finely comminuted crystal debris will be found as before. Such larger areas of crystalline material will, as we have already seen, grow preferentially, the matrix being deposited on them when recrystallisation occurs. Hence, as they gradually increase in size, this fact of itself, and also as a result of their greater rarity and effectiveness as nuclei, will tend to produce crystals of gradually increasing dimensions in the annealed state. As we have seen, the passage from the small superficial crystals to those of the coarse band is gradual and not abrupt, which is as it should be on the surface tension hypothesis. Further, the smaller the strain to which the material has been subjected, provided of course that the yield point has been surpassed, the coarser will the structure of the annealed metal be. This, however, cannot go on indefinitely, since only when the elastic limit has been exceeded is there any debris along cleavage planes, and at the crystal boundaries, to cause crystal growth by their union with the unchanged parts. Hence from about the yield point another zone of essentially unaltered crystallisation is found.

A very complete explanation is thus afforded of the triple nature of the annealed structure, but the surface tension theory will carry the subject further and the influence of the temperature of annealing can be accurately predicted.

At temperatures below a certain minimum the viscosity of the material will obviously preclude the possibility of any regrouping of parts. At higher temperatures, however, a point is reached at which the difference of solution pressure between the minute crystal remains of the crushed debris, and the larger unchanged crystalline islands will assume such a value that growth of the latter at the expense of the former will occur. This growth, however, will, in its earliest stage, occur only where conditions are most favourable, *i.e.* where there remain a comparatively small number of crystalline parts of fair size embedded in a considerable quantity of crushed matrix. The coarse-grained material found after annealing is therefore strictly localised, and only material subjected to just such a stress as to yield this condition will show marked growth. Thus it is that Sauveur, using the low temperature of 650° C., was led to postulate a

critical stress as necessary to cause the coarse crystalline growth, only a very narrow margin separating material in the ideal condition for growth from that which is too slightly, or, on the other hand, too strongly deformed. As a higher annealing temperature is utilised, however, less favourable structures are rendered sufficiently mobile to reform and thus produce a grain growth, and regions stressed to a widely different extent take part, the critical stress disappearing, as Chappell showed beyond doubt.

The foregoing explanation, based on fully established facts regarding surface tension, is quite independent of any special property of iron. It should therefore occur, if the hypothesis be true, that a corresponding coarse grain growth should be found under suitable conditions in other metals. That Robin [1] has observed this in many metals and alloys is, therefore, exceedingly valuable confirmatory evidence. The explanation put forward by that investigator is exceedingly like that given here, lacking, however, the consideration of the effects of surface tension as operating in (*a*) retarding the commencement of growth in the over-strained part until a comparatively high temperature is reached, (*b*) in determining the influence of the size of the large crystalline residues, and (*c*) in determining the effect of the temperature of reheating.

This subject has been treated in great detail on account of the remarkable confirmation which it supplies to the fundamental idea that there does exist a surface tension between the grains of ferrite. It is inconceivable that if the basis idea were erroneous the conclusions arrived at should coincide so absolutely exactly even in the smaller details with experimental discoveries. The recrystallisation of deformed iron is a further instance of great industrial importance in which the value of the theory is evident.

Some Effects of Surface Tension on Steel.

Recent results obtained by Professor Howe on the coalescence of ferrite and cementite needles and cell walls into more rounded

[1] Robin, *Revue de Métallurgie, Mémoires*, 1913, vol. 10, p. 722.

patches as a result of annealing[1] have already been ascribed, with perfect justification as the author believes, to the influence of surface tension in tending to reduce the area of contact of the different phases present. Thus Professor Howe remarks, "The network system is a transient arrangement. Surface tension is always striving to break it down, and in the end to assemble all the cementite in one mass and all the ferrite in another."

Portevin has used the idea in a similar manner, so that with these aspects of the influence of surface tension upon the structure of steels it is unnecessary to deal here. In passing, however, reference may be made to Figs. 7 and 5 of the author's earlier paper as illustrating excellently this effect, which incidentally reduced the elastic limit of that particular steel from 17·5 to 4 tons per square inch.

Sulphide inclusions in steel exhibit well the effect of surface tension in rounding their outlines so that in the cast state they are in general perfect spheres. From the point of view of the present paper, however, their effects in other directions are even more interesting. In the literature of metallurgical research terms such as "nucleus," "germ," &c., are exceedingly common. The influence of nuclei are often of paramount importance, but it does not appear to have occurred to many writers that their *modus operandi* is evidence of surface phenomena. It has been already noticed that it is often impossible for drops of liquid to form in a supersaturated, dust-free vapour on account of the profound influence of surface tension upon very small drops, while under ordinary conditions dust particles present offer an already considerable surface for condensation. In much the same way do nuclei facilitate by their presence the initial stages of the precipitation of new phases. This fact has probably something to do with, for instance, the falling out of cementite from a supersaturated steel on cooling from above the cementite line at the crystalline boundaries, since here the impurities may be supposed chiefly to find lodging. The particular example of this influence of immiscible impurities which will here be considered is the effect of manganese sulphide and slag in deter-

[1] *Proceedings of the American Society for Testing Materials*, 1911, vol. 11, pp. 279, 295; *International Journal of Metallography*, 1911, vol. 2, October, p. 13.

mining the banded structure of, for instance, a boiler-plate. When such a steel cools down to Ar3 there is the tendency for the precipitation of ferrite. Now in the complete absence of all extraneous material the difficulty for the precipitation of the first particle of this of almost molecular size would be very great as a result of surface tension forces. The difficulty, however, is removed if there is available a surface already of appreciable size on which ferrite can be deposited. As Brearley[1] has shown experimentally the sulphide or slag rods do afford such surface, with the result that around each such non-metallic inclusion a thick envelope of ferrite forms, leaving the spaces between to be filled up with pearlite. The banded structure of such a steel is thus absolutely determined by surface tension phenomenon, and affords another excellent illustration of the profound importance of this property of matter in its practical application. This explanation meets fully the objection raised by Professor Howe to Mr. Brearley's interpretation of facts. Professor Howe asks,[2] "By what piping does this Pied Piper entice the ferrite from within the austenite, draw it across considerable distances, and enwrap itself in it as in a garment?" The ordinary course of diffusion together with the surface tension effects thus afford a complete answer to this question.

The explanation of the properties of hardened steels and of the effect of tempering upon them is one direction in which it is obviously of interest to apply our hypothesis. As will be shown, it is capable of yielding exceedingly suggestive results and of explaining a wide range of facts without, moreover, resorting to assumptions such as that of interstrained iron made by McCance, or of the influences of crystal twinning of Professors Carpenter and Edwards.

Perhaps the most direct way of approaching the subject is by considering some results contained in the paper on "The Magnetic and Mechanical Properties of Manganese Steel," by Sir Robert Hadfield and Professor Hopkinson.[3] Briefly it was there shown that the effects of reheating an "austenitic" manganese steel was to render it increasingly magnetic, hard, and brittle.

[1] *Sheffield Society of Engineers and Metallurgists*, 1909, p. 56.
[2] "Metallography of Steel and Cast Iron," p. 280.
[3] *Journal of the Iron and Steel Institute*, 1914, No. I. p. 106.

The following table gives a few of the typical results obtained :

Treatment.	Specific Magnetism.	Hardness No.	Angle of Bend.
W.T.	Non-magnetic	207	180° Unbroken
400° C. for 6 hours . . .	0·2	340	12°
450° C. „ 48 „ . . .	7·0	418	$1\frac{1}{4}$°
500° C. „ 60 „ . . .	42·0	444	nil

The magnetic and mechanical properties indicate beyond doubt a change from the "austenitic" to the hardenite condition which is abundantly confirmed by the micrographs. On p. 116 the authors remark that "the change from the ductile to the brittle condition is accompanied by well-marked changes in the microstructure of the steel . . . the usual water-toughened form with fine-grained polygonal structure passing into the needle-like form which bears a considerable similarity to a martensitic steel."

It is now usually considered that in austenitic steels such as the manganese one under consideration, the carbon is in a state of perfect solution. Now there can be little doubt that the explanation of the structure of "hardenite" or "martensite" given by Professor Arnold and Dr. McWilliam is correct. This explanation is based upon the well-known tendency for ferrite or cementite, as the case may be, to fall out of solution during even the most rapid quenching in the case of ordinary steel, especially upon the cleavage planes, which are therefore emphasised, and in certain cases give rise to the interlacing needle-like structure which by some has been considered to be characteristic of this constituent. Without dwelling further upon the origin of the structure there is every reason to believe that it is no longer homogeneous as in austenite, but duplex with unaltered solid solution and precipitated ferrite or carbide microscopically beyond recognition. In Hadfield and Hopkinson's manganese steel a series of "interlacing lines" was noted in the reheated hard samples. Now such a micrographic change, which from a homogeneous solution yields a duplex constitution, results in the formation of a most intimate series of boundaries at each of which surface tension must make itself felt, with the result that a strong scaffolding begins to strengthen the mass with a con-

sequent increase of hardness. Further, this increase must be in some manner related to the extent of the micrographic change, or in other words, to the duration and temperature of the annealing, as the tabulated results clearly show.

The general hypothesis would also, however, suggest that the increase in the hardness produced by the reheating should not be without limit. When a more or less complete resolution of the "austenite" into its constituents has occurred and further annealing tends to produce coalescence of the already formed particles (the troostitic stage), the surface area between the constituents across which attraction can occur is a maximum, and thereafter decreases. Hence it should be possible to produce to a certain extent at any rate a softening by further heating beyond that point which yields the maximum hardness, a fact, however, which was not observed during the greatest time used.

Two other points arising from the work performed for this research are of interest. The explanation of the structure and properties of hardenite does not in any way depend, being physical and not chemical, on the actual chemical composition, and it is therefore of interest that in replying to the discussion on their paper the authors say "those figures suggested that the change in carbon did not appear to play an important part in the change in the quality of the material from non-magnetic to magnetic condition." Almost the same explanation is available in other cases than that of hardened steel to account for similar changes in properties due to the partial break-up of a solid solution as occurs in several of the copper alloys, *e.g.* copper-aluminium.

The second point arises from the statement of Hadfield and Hopkinson,[1] where "it was suggested that the important part in the treatment was probably the speed of cooling rather than the prolonged heating which preceded it." Such a result is entirely in accordance with, and indeed might have been deduced from, the surface tension hypothesis of the increase of hardness, since an annealing above the critical range, where no decomposition occurs, can yield no surface of separation at which surface tension can act. Further, as the extent of the decomposition of the solution increases with time, this factor is of vital importance in determining to what extent the necessary surfaces are produced.

[1] *Journal of the Iron and Steel Institute*, 1914, No. I. p. 106.

It is necessary to add very little to the foregoing to explain the properties of an ordinary hardened carbon steel upon the same basis, since the same series of changes are undergone though at a greatly increased rate, and the influence of tempering may be equally readily understood. Starting with a steel in which the whole of the carbon is in complete solution, the form usually designated "austenitic," we have already followed the first change which results in a partial decomposition, hardenite being formed, with, as a result of attractions set up at each surface of

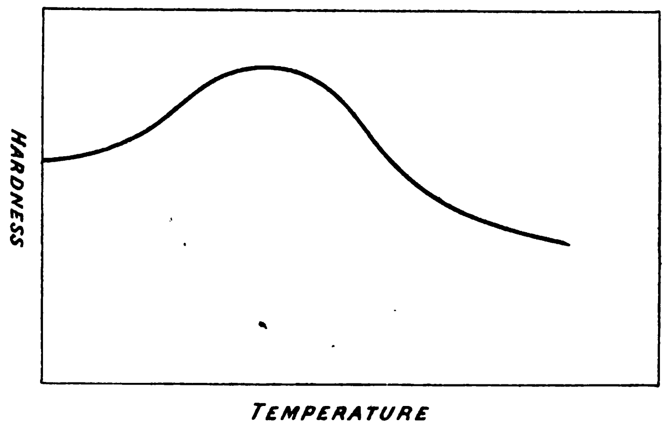


FIG. 4.

separation, a greatly increased hardness. The hardness becomes a maximum under the theory when the greatest surface is present. A further tempering, however, producing growth in the products of the disintegration of the solution, reduces the maximum surface area and hence softens the material. In Fig. 4 is shown the theoretical course of the influence of tempering upon an austenitic steel which will be compared with the actual curve as soon as conditions allow.

Passing on to a brief consideration of the influence of the presence of special elements in the steel, it was mentioned in the earlier paper that the refining influence of nickel, manganese, vanadium, tungsten, or chromium upon the structure of a steel was readily explicable on the assumption that surface tensions existed between each grain and crystal. That the growth of

crystals upon annealing is the result of the tendency of such surface forces to diminish the areas across which they act is almost beyond doubt. It is a hypothesis which has been frequently used, and is merely a special instance of the general tendency of a system to assume the form with the minimum potential energy.

Now if the elements mentioned act as impurities often, though not invariably, do, and lower the surface tension between the crystals, then that very factor which actually determines growth is less effective, and for similar treatments the structure of the special steel will be finer than that of a plain carbon one. Since, further, the lowering of the surface tension increases as the quantity of the added "impurity" increases, the grain refining action will, within certain limits, increase with the amount of the special element present. At any rate in the case of the nickel steels this is an established fact.

It is, however, possible to follow the argument in a further and exceedingly important direction. Not only does such a theory offer a rational explanation, so far as the author is aware for the first time, of the refinement of the crystalline size brought about by the addition of certain elements, but it indicates that the same additions, and for a similar reason, increase the resistance of the steel to tempering. In Fig. 5 are produced the heating curves of two steels determined respectively by (*a*) Arnold and (*b*) Osmond. Curve *a* was obtained on a hardened steel containing 0·89 per cent. carbon and 0·09 per cent. manganese, while the material on which curve *b* was determined contained 0·23 per cent. manganese. The retardation produced by even 0·2 per cent. of manganese on the evolution of heat which occurs when the velocity of tempering reaches an appreciable value is readily apparent.

There are two instances of immense practical importance in which this idea affords an absolutely new light. In the first case, as we have already seen, the effect of the special element which lowers the interfacial tensions in retarding the change and growth which accompany a tempering action increases as the quantity of that element is increased. We have also already seen that manganese, as far as it is at present possible to judge, exerts such an influence upon the surface tension. It is there-

fore reasonable to expect that where a sufficient content is present to exert its full influence no appreciable resolution will occur even on ordinary air cooling, or in metallographic terms the steel is austenitic. In both high nickel and high manganese steels this is found. That the explanation of the curious nature of

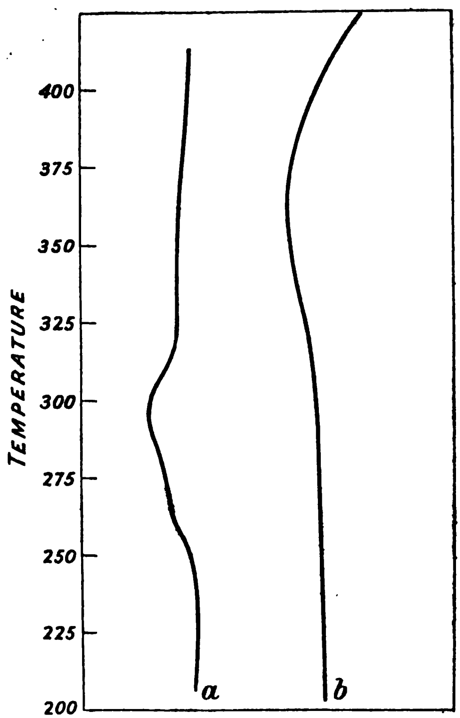


FIG. 5.

the Hadfield manganese steel is due to such a slowing up, as distinct from a total suppression, of the change from the solution to the pearlite state is clearly shown by the fact that, as Hadfield and Hopkinson have shown, the Ar1 point is still present about 674° C. even with $12\frac{1}{2}$ per cent. of that element.

The increased "thermal stability" of the tungsten and high-speed steels, *i.e.* their increased resistance to softening under heat, is another example of a similar type. As a result of the lowering

of the surface tension effects produced by the addition of the special elements present (which, here again, is a function of the amount of the added elements), the decomposition of the solid solution into a pearlitic condition experiences a retardation.

A final example of the influence of surface tension upon the structure of steel may be offered which amounts to almost proof positive that such forces are at work.

Besides, the tendency to produce masses in the spherical form around which it acts, perhaps the most characteristic effect of surface tension is in the production of drops from a jet. This arises from the condition of instability of long cylinders under such forces and their consequent break up into other forms. A careful study of the changes which annealing below the point Ac1 produces in the structure of pearlite shows that an exactly similar effect is to be observed. That long annealing of a high carbon steel at say 650° C. produces a spheroidal pearlite is of course well known, of which Fig. 6 (Plate VI.) offers a typical example. When this is compared with Fig. 2, in which surface tension has admittedly been the cause of the spherical form of the crystal drops, the feeling that the same cause must have been responsible for the same effect in the steel is very strong.

The matter is clinched, however, by the examination of intermediate forms (Figs. 7, 8, 9, Plate VI.). The final spheroidal masses of FeC_3 are not the result of the globularising of individual plates as might at first appear, but are the result of the break-up of these into drops. Benedicks has already mentioned a variety of pearlite in which this break-up is in the course of proceeding, and a swelling and thinning out can clearly be seen in the marked areas. In Fig. 8 can be seen the coalescence of two distinct globules.

The excessively important rôle which surface tension appears to play in such directly practical fields as the annealing of cold-worked metals, the influence of slag in determining the banded structure of a boiler plate, the tempering of steel, and the influence of special elements thereon, and the manganese, self-hardening, and high-speed tool steels, renders a detailed study of its mode of action eminently worth while. The theoretical and inductive treatment here accorded will pave the way later for an experimental one.

CORRESPONDENCE.

Dr. W. H. Hatfield (Sheffield) wrote that he had read Dr. Thompson's able paper with considerable enjoyment. The mental agility displayed could not fail to evoke admiration and, from a theoretical standpoint, the author must be congratulated upon having produced an interesting piece of work. Unfortunately, it was an example of hypothesis built upon hypothesis, and it would perhaps be well to study the fundamental ideas upon which the author's conception rested. First of all the idea of an amorphous film between the crystals was, in itself, pure hypothesis. What kind of a film was it? What was the mechanism of its production? Dr. Rosenhain had advanced a plausible theory of its origin based upon the assumption that the crystal unit contained a minimum of molecules or atoms and that there was obviously an invariably small surplus of non-crystalline matter which thus constituted the amorphous films. It should, however, be noted that Dr. Rosenhain had already discarded that theory, and it would appear that Mr. Humfrey's suggestion of the effect of opposing crystals upon the remaining material between them now held the field. The latter view obviously presupposed a variable physical condition of the material ranging into the crystals from the amorphous film. How would such a variable physical condition, within the limited range, affect Dr. Thompson's view? Even supposing Humfrey's theory proved tenable, it remained to be agreed as to what the properties of such an amorphous phase might be.

The meaning of the term surface tension when applied to liquids was understood, but when solids were in question such a factor sank into relative insignificance. The author illustrated his point with an inconclusive picture of a dendrite of lead; had he studied such dendrites of steel? There were a number in existence, excellent examples. If so, he would have failed to notice any such effect, and he (Dr. Hatfield) would require much more experimental evidence in support of the author's theory before he could really consider it very seriously. Had not the author better give more attention to tension between surfaces (a very different thing from surface tension), and to consider whether such tension of considerable magnitude presupposed an amorphous layer? Instead of building on his theory, would it not be better if Dr. Thompson first of all gave a little more attention to explaining his fundamental conception of the process of the action in which he claimed surface tension took such an important part. Would he kindly explain the mechanism in detail as applied to solids, instead of simply assuming that similar conditions obtained as in the case of liquids. For instance, what would be the effect in an undercooled liquid such as glass, fused silica, &c. Also it might be interesting if Dr. Thompson could state the difference in strength in tension, say, of a column of glass and of a

similar column cut in two at right angles to its axis, the strength being dependent on the surface tension of a film of liquid, normal or undercooled, interposed between the planes. Admittedly some working theory was required to explain many facts which at present could not be correlated in the manner Dr. Thompson attempted in his theory, and it would be certainly of considerable value if he were able finally to substantiate his point of view. To deal properly from a purely steel metallography standpoint with the ground covered by the author would need greater space than a contribution to the discussion would permit, but there were a few points which should be mentioned. Dr. Thompson, on p. 156, discussed the difference in tensile strength of two specimens of iron, one 21·1 tons and the other 21·8, and argued somewhat elaborately on the difference, 0·7 of a ton. Did it not occur to him that without theorising at all easy explanations of such a small difference could be found? For instance, the carbide might not be distributed exactly in the same manner, or even in the same quantity, in the two portions of the material which produced the fractures. Again, the question of inclusions and variations in mechanical manipulation of the actual tensile testing were all sources of possible error which might vitiate any calculations made. On p. 167 Dr. Thompson spoke of the impurities being usually found at the boundaries of the crystals. That was not so. In the case, for instance, of slag inclusions, the author would be aware that they were frequently, it might almost be said generally, contained in the crystals, and on his own theory would form nuclei for the formation of those crystals. He (Dr. Hatfield) did not consider that Drs. Arnold and McWilliam's views with regard to the nature of austenite and hardenite had been correctly stated, and it would be of interest if the author could prevail upon Professor Arnold to state in the discussion his present conception with regard to those two constituents. It would appear from his (Dr. Hatfield's) observations that martensite or hardenite consisted essentially of solid solution, and that was broadly confirmed by the heat evolved when tempering took place. If that were so, Dr. Thompson's view as to its constitution would be incorrect. As to steel breaking through the crystals instead of between them, had not too definite a law been laid down upon that point based upon too little data? He (Dr. Hatfield) was of the opinion that rupture took place between the crystals much oftener than was supposed, and he thought that was a question which merited a good deal of further investigation. Speaking generally, endeavour had been made to explain pretty well the whole facts and debatable points of steel metallography by means of the hypothesis, and he felt that the author had attempted to bring within his vision too large a range of subjects to obtain a suitable discussion of them. At the same time he fully appreciated the effort which was being made to provide an interesting explanation of many outstanding facts which were certainly in need of correlation within some such working theory.

Dr. W. Rosenhain, F.R.S. (Teddington), wrote that he had read Dr. Thompson's paper with very great interest; he regretted that time had not been found for the reading and discussion at the meeting of a paper of such wide scientific interest. Dr. Thompson's paper was, of course, admittedly, highly speculative, and that character must be carefully borne in mind by those reading—and criticising—it, but it was none the less valuable on that account, since legitimate and sound speculation should rightly form the basis for future research. Incidentally he (Dr. Rosenhain) wished to express his pleasure at the appreciation of his criticism of Dr. Thompson's previous paper on the subject; it was evident that criticism which led to the writing of such a paper as the present one was well justified, if only on that ground. For that reason he now proposed to subject Dr. Thompson's interesting speculations and arguments to further scrutiny.

In the first place, Dr. Rosenhain was pleased to note again how entirely Dr. Thompson's views were based on an acceptance of the hypothesis put forward by him (Dr. Rosenhain) some years ago as to the existence of a thin layer of "amorphous cement" between the crystals of a crystalline aggregate such as a metal. The whole of Dr. Thompson's arguments were based on that acceptance, and the divergence of views between himself and Dr. Thompson only began when it came to accounting for the cause from which this intercrystalline cement derived its evident hardness or its hardening effects. On Dr. Rosenhain's original hypothesis, to which he was inclined still to adhere, this amorphous cement was essentially and inherently hard and non-ductile, while on Dr. Thompson's view it was not particularly hard, but owed its hardening effects to the action of surface tensions at the boundaries between amorphous cement and crystalline matter. Taking the first hypothesis, Dr. Thompson suggested that great hardness in the amorphous material was a violent assumption, and then proceeded by an ingenious calculation to show that the "cement" would need to have a tensile strength of some 550 tons per square inch. Any such figure would, of course, be a fatal objection if it could be upheld, but in Dr. Rosenhain's opinion it was quite an unnecessary figure to assume. First, as to the hardness of an amorphous material. This fundamental idea had been taken from Beilby's work, in which hardness and brittleness was always regarded as associated with the amorphous condition—indeed, the main burden of all the evidence adduced by Sir G. Beilby went to show that plasticity and ductility were properties of crystalline matter, while hardness and brittleness were equally characteristic of the amorphous. The nature of plasticity was now so well understood that this conclusion might be regarded as pretty safely established. Plasticity or ductility in a metal was known to depend upon the process of slip within the crystals, and such a process was entirely dependent upon the regular arrangement of the atoms on space-lattices which allowed of the existence of regular cleavage or gliding planes. Now, in an amorphous substance—by definition—this arrangement of atoms

on regular space-lattices did not exist, and consequently there were no cleavage or gliding planes along which slip or deformation could occur. The amorphous substance therefore possessed no plasticity or ductility, and underwent only elastic deformation up to the point of rupture; but this point of rupture was necessarily higher than the point at which plastic yielding would commence—just as it took much greater force to pull apart two well-fitting plane surfaces than it did to make them slide over one another; in the one case the direct attractions across the plane of separation had to be overcome, while to bring about sliding a tangential stress was required, which was only a fraction of the direct attraction.

In these strictly logical deductions from known facts we were further supported by our knowledge of the properties of known amorphous substances, such as glass, which were characteristically hard and brittle; indeed we might carry the matter further and point to the essential hardness and brittleness of liquids—water under tension behaved as a very hard and brittle substance, and we all knew how easily it was shattered by a blow. A more serious argument was the hardening which occurred in metals as a result of cold work, but here no doubt Dr. Thompson would again introduce the play of surface forces, so that argument was perhaps better postponed.

Next, as to the magnitude of the strength or hardness of the amorphous cement, Dr. Thompson gave an interesting example of how he had arrived at the absurd value of 550 tons per square inch. It must first be pointed out that the whole of his argument was based on an assumption as to the thickness of the amorphous layers. It was true that he clothed this assumption in the guise of a calculation, but it was purely an assumption none the less. Beilby's estimate of the thickness of the amorphous layer produced by polishing on the surface of a crystalline substance (carbonate of lime) was obtained by direct and careful experiment and was therefore worthy of great weight, but it was not by any means directly applicable to the question of the thickness of the amorphous films between adjacent crystals. The Beilby surface film, as sketched in Dr. Thompson's reproduction of Beilby's diagram, had been produced by mechanical disturbance of the surface by what was in reality a very gentle process, viz. polishing. What evidence was there to justify the view that the films between crystals were of even the same order of thickness? In his (Dr. Rosenhain's) view the thickness of the inter-crystal films depended entirely upon the effective radius of action of the orienting forces which emanated from the atoms of each of the adjacent crystals, or rather upon the range of distance over which the opposing orienting forces of the two crystals were able to neutralise one another; this could only be settled either by direct experiment or by a knowledge of the form of the law of force governing these actions. Such figures as those given in the paper were by no means adequate to settle the matter, although their usefulness might be freely admitted to the extent of serving to show that here was a fundamental matter urgently calling for experimental investigation. Such experimental

investigation he (Dr. Rosenhain) had planned some four years ago, but it was not, of course, possible to pursue the question in present circumstances.

Dr. Thompson's calculations regarding the supposed thickness of the amorphous films required criticism from another point of view. It was distinctly surprising to find Dr. Thompson's calculation based not on the elastic limit of the steel, but on its ultimate stress. Now by the time the steel broke at this stress it had undergone a very considerable amount of plastic deformation and new quantities of amorphous material had been brought into existence, so that the calculation of the relative amounts of inter-crystal cement in the steel in its two conditions was really quite inapplicable. Further, the calculation given in the paper assumed that the difference in tensile strength between the material before and after normalising was solely and entirely due to the difference of crystal size, and the resulting difference in the amount of crystal boundary. But was such an assumption reasonable? During normalising the natural growth of the crystals was intentionally inhibited by rapid cooling, and there was very considerable doubt also whether the distribution of the carbide was really identical in the two conditions. Dr. Thompson dismissed this vital point with the remark that under the microscope the distribution of carbide appeared to be much the same in the two cases, but this was not adequate. If as the result of the rapid cooling which occurred during normalising the inter-crystal layers of amorphous metal should prove to be thicker than those resulting from slower cooling, or if the carbide distribution was appreciably different—as, for instance, by a very small amount of carbide remaining in suspension in the ferrite—the whole fabric which Dr. Thompson based on his calculation would require reconstruction. Dr. Rosenhain therefore considered that before Dr. Thompson could suggest that the hypothesis of a hard and strong intercrystalline cement required absurdly high values for the strength of that cement, he would need to bring forward definite experimental evidence to prove the thickness of such cement layers in definite cases, and to show how the strength, or rather the elastic limit, varied with that thickness. This was, admittedly, a large demand, but the real value of such discussions lay in defining the experimental problems which must be faced before theoretical advances could be consolidated.

As bearing upon this question of the probable strength of the amorphous phase of a metal, it was interesting to recall an observation made some years ago by H. Le Chatelier, who pointed out that in many cases, when a ductile metal or alloy was hardened by cold work, the tensile strength could be increased—at the expense of ductility—to a value in the neighbourhood of twice that of the metal in the fully annealed condition. It was not, of course, suggested that this was an accurate or universal rule; in the case of many steels particularly, it broke down entirely, but it applied roughly to several of the pure metals. Now, as Beilby had shown, even the most severely cold-worked

metal was still far from being entirely amorphous, but the line of fracture must, in such a material, necessarily pass through a considerable quantity of the amorphous phase. It would seem, therefore, that the strength of the amorphous phase must be more than double that of the crystalline, but that it was probably not more than three or at most four times as strong. This was obviously only a very rough approximation, but it did furnish some sort of guide to the order of strength which might reasonably be looked for in amorphous metals.

The bulk of Dr. Thompson's paper was occupied with a very interesting endeavour to demonstrate that surface-tension existed and played a part in the phenomena of metals. With this general proposition he (Dr. Rosenhain) naturally agreed, but the divergence arose in regard to the magnitude of the surface-tension as between the crystalline and the amorphous phase of the same metal, and as to the degree of the influence of surface forces in such phenomena as strength and ductility. The view previously expressed by Dr. Rosenhain that, owing to the similarity of density as between the crystalline and amorphous, no large surface-tension could exist between them, was met by Dr. Thompson's reference to the relatively high tension of a surface between oil and water, even where the oil had nearly the same density. This example of Dr. Thompson's served to show that he (Dr. Rosenhain) had not expressed his point of view correctly in referring to the "densities" of the two media, although even from that point of view the oil-water case was not strictly comparable with the other, since the oil and water do not "wet" one another. However, what he had in mind in regard to the inter-face of crystalline and amorphous material of the same chemical composition was this, that the surface forces arose from unbalanced molecular forces at the surface of a solid or liquid. Where one was dealing with a "free surface," an atom or molecule in the surface was attracted by the surrounding atoms of liquid or solid, these attractions acting upon it from all directions included in a hemisphere with the atom at its centre and its diametral section in the surface, but the attractions acting upon it from the remaining hemisphere were nil, or negligible. If, however, the second hemisphere were filled with atoms or molecules of the same kind, merely differing slightly in arrangement or "density" of packing, then the resultant, in one direction or another, would only be due to the difference effect due to these two sets of attractions. Of course, if both sets of attractions were extremely large, then even such a difference might have an appreciable value; but here again we must wait for definite experimental evidence, which as yet was not forthcoming. It had recently been suggested that the "internal or intrinsic pressure" of a solid might be regarded as a measure of its cohesive forces, *i.e.* of its mechanical strength. If this view could be substantiated, then we found at once a relation between surface-tension and mechanical strength, not necessarily implying that the surface-tension was the cause of the mechanical strength, but that it merely arose because high surface-

tension and high mechanical strength both followed from a high value of Laplace's K (intrinsic pressure).

This last consideration might perhaps prove of interest as bearing upon Dr. Thompson's application of the amorphous cement plus surface-tension theory to alloy steels. He put forward the idea that the alloyed elements lowered the surface-tension in these special steels, and thus brought about their peculiar behaviour in regard to thermal transformations. If this view were correct, however, it should imply that these added elements in lowering surface-tension also lowered the intrinsic pressure—but this would imply a lowering of the cohesion and therefore of the strength of the steel. The only way out of this difficulty would be to assume that the alloying elements did not lower the actual surface-tension of one of the phases—say, the crystalline—but did lower that of the other, in that way reducing the relative surface-tension while only lowering the intrinsic pressure of one phase—in this case, of the amorphous. If this assumption were correct, whether we accepted Dr. Thompson's ideas as to the effects of surface-tension or not, cold-working should produce less hardening in these steels than in plain carbon steels. This, at all events, was a point capable of experimental test, but existing data did not furnish the sort of exact comparison required.

Dr. Rosenhain was particularly interested in two further points raised in Dr. Thompson's paper. The first of these was the theory of the hardening of steel which was advanced in the paper. Dr. Thompson would find that theory set out in considerable detail in the first place in the discussion by the present writer of a paper by Professors Carpenter and Edwards in 1914 in this Journal, and more fully in his (Dr. Rosenhain's) book on "Physical Metallurgy." The only point of difference between the writer's theory and Dr. Thompson's being—as before—that while Dr. Rosenhain attributed the hardening effect of the innumerable minute amorphous films around the incipient crystals of alpha-iron to the intrinsic hardness of the amorphous material, Dr. Thompson ascribed their hardening effect to surface-tensions, brought into play by their tenuity and large surface area. That divergence, however, was a matter of manner rather than method, and left the two views in substantial agreement as to the structure and constitution of hardened steel. Further experimental research would serve to show which—if either—of these divergent views was right.

He would deal only with one other point—"slag enclosures." He (Dr. Rosenhain) himself had for some time shared the view adopted by Dr. Thompson and many others, that such enclosures served as nuclei for the crystallisation of ferrite—a view originally put forward by Ziegler (a Russian metallurgist) in the *Revue de Métallurgie*. Evidence shown him by Dr. Stead, however, and his own observations continued over a number of years on the banded structure of steel such as was seen in boiler-plates, had convinced him that the association of the enclosures

with the ferrite bands was an effect rather than a cause. In the first place, banding did occur in the absence of enclosures, although that might be explained by assuming that there were "invisible enclosures" present. The true cause of banding, however, lay, he believed, in the segregation of phosphorus towards the crystal boundaries during the original solidification of the steel. That phosphorus only diffused very slowly during subsequent treatment, and the steel originally constituting the outer layers of the crystals became rolled out into sheets and bands. This process could be readily traced by the use of one of the "cupric" etching reagents. The manner in which the original dendrites became elongated into bands could be very clearly watched from stage to stage through the rolling process. At each time of heating, the carbon diffused and then the pearlite separated again on cooling, but the regions high in phosphorus resisted the entry of carbon and thus remained as ferrite bands throughout. Now it was natural that the non-metallic enclosures should in the first place be found in the inter-crystal boundaries in the solidified ingot—in that way they became associated with the high-phosphorus regions and remained associated with them throughout. Some of the enclosures, however, were trapped by the growing crystals of the ingot and enclosed in them instead of being pushed out to the crystal boundaries; these were the isolated enclosures which were found in most steel, embedded indifferently in the general pearlite structure, without having served as nuclei for ferrite at all. It would occupy too much space, and require extensive illustration, to furnish the evidence for the various steps indicated, but it might be pointed out that by a really prolonged annealing at a temperature above the critical range, the ferrite bands could be made to disappear, in spite of the persistence of the non-metallic enclosures. This could be readily accounted for by the gradual diffusion of the phosphorus—but what then became of the nucleus action of the enclosures?

Dr. Rosenhain felt that he must apologise for occupying so much space in discussing Dr. Thompson's paper, but it raised questions of the greatest interest and importance. Dr. Thompson had begun by accepting the fundamental proposition of the hypothesis put forward by him, and had added to it the further conception that the effect of the amorphous films present between the crystals of a metal was really due to surface-tension forces. He (Dr. Rosenhain) had, both now and in his previous comments on Dr. Thompson's papers, taken the opposite view, viz. that it was not necessary to invoke the action of such forces, and that these forces were not really as large and important as had been suggested. Admittedly, however, much of the argument on both sides was of a more or less speculative kind—in fact, it was the very speculative nature of what Dr. Thompson had put forward which rendered searching criticism necessary and desirable. If Dr. Thompson's hypothesis survived not only that criticism, but the much more searching tests of experimental verification which would have to be

applied to it in the future, then he (Dr. Rosenhain) would be only too glad to welcome it as a valuable further step in our knowledge of the inner mystery of metals.

Dr. F. C. THOMPSON wrote in reply that, with respect to Dr. Hatfield's interesting remarks, the amorphous film theory had been taken for granted. The question of the origin of the film, however, was in one particular of importance. As he (the author) had shown in his first paper connecting surface tension with the mechanical properties of metals,[1] an origin such as that first proposed by Humfrey, in which a gradual change in molecular orientation was assumed to occur between adjacent crystals, would result in a very marked lowering of the surface tension attraction between them, and therefore a lessening in the effects due to such an attraction. Dr. Hatfield had stated that "the meaning of the term surface tension when applied to liquids was understood, but when solids were in question such a factor sank into relative insignificance." The only reply to such a statement that could be made was a direct contradiction. The surface tensions of $CaSO_4$ and $BaSO_4$ in the solid state had been measured, and were of the order of a hundred times the surface tensions for most liquids. Dr. Hatfield appeared to have failed to realise the importance of the "inconclusive picture of a dendrite of lead." Dr. Thompson was fully aware that in steel such dendritic formations showed no appreciable rounding off at the corners, but that did not affect at all the point under consideration. The value of the lead dendrite lay in the fact that it afforded conclusive evidence that surface tension, to which alone the rounding off of the corners could be attributed, did make itself felt between the crystalline and the non-crystalline states of the same pure metal. That in other cases the influence of surface tension was not sufficient to overcome greater mechanical strength did not affect the argument; the lead had shown that a surface tension did exist. Dr. Hatfield took the author to task for examining too large a range of subjects, but such an extended view was deliberately taken with the intention of showing how wide the influence of surface tension might be, not necessarily was.

Dr. Thompson was most pleased that Dr. Rosenhain had been able to contribute at such length to the discussion, since it was largely his earlier criticism which had given rise to the present paper. Dr. Rosenhain's discussion of the mechanical properties of glasses was most interesting, and added considerably to any value which the paper might have. Briefly Dr. Rosenhain's position appeared to be that he was still unconvinced by the evidence brought forward that surface tension exerted any appreciable influence upon the properties and structures of metals. Further experimental evidence alone could dispel such incredulity, which the author hoped to be able to supply in the course of time.

[1] *Transactions of the Faraday Society*, 1916, vol. xi., part i., p. 104.

With regard to the calculation of the strength of the films around the crystals which, when based upon the maximum stress, gave the amorphous modification of iron a tensile strength of 550 tons per square inch, a calculation based upon the elastic limit would merely make the strength greater still, say 2000 tons per square inch, which rendered the simple hard modification hypotheses more than ever untenable.

Dr. Rosenhain's observations with regard to the banded structure in steel were of great interest, and offered a very direct mode of studying the possible effects of surface tension which would be taken up. So far it did appear that the nucleus theory appeared to miss several important points, but a fuller discussion was postponed till the author had the opportunity of repeating the experiments suggested.

THE CASE-HARDENING OF IRON BY BORON.

BY PROFESSOR N. TSCHISCHEWSKY (TOMSK, RUSSIA).

On an inspection of the diagram of iron-boron alloys [1] it will be seen that on cooling these alloys the boron is not wholly combined in the form of borides of iron, but a proportion of it is left in the form of a hard solution.

This phenomenon suggests the possibility of case-hardening steel by boron, similarly to the case-hardening of iron by carbon.

Alloys of iron with boron are remarkably hard, so that they can scarcely be treated on an emery-wheel. The technical application of case-hardening by boron suggests itself therefore as a feasible industrial operation.

The complete cementation that takes place in carbon steel is not the type of operation the author has in mind, but a surface cementation. It is more convenient to obtain a ferro-boric alloy by melting on account of the high price of boron, and also to secure its complete use without wastage.

The use of boron is not perhaps suitable for armour plates, because of its comparative scarcity, but for some machine parts and, generally speaking, where much wear occurs, boron can be applied with success.

It must be pointed out that while annealing is necessary in order to confer the necessary hardness on articles case-hardened by carbon, boron confers hardness without the necessity of any special heat treatment.

To ascertain the conditions of case-hardening by boron, the author took a sample of iron of the following composition:

	Per Cent.
Carbon	0·12
Silicon	0·02
Manganese	0·16
Phosphorus	0·06
Sulphur	0·04

And as a case-hardening powder, pure amorphous boron and a finely powdered rich alloy of iron with boron containing about 19 per cent. of boron were taken.

[1] N. Tschischewsky and A. Herdt, *Journal of the Russian Metallurgical Society*, No. 4, 1915; *Iron Age*, August 24, 1916.

The pieces of soft iron used were in the shape of cubes, holes being drilled in the centre to a depth of about half their length. These holes were filled with fine amorphous boron, or with powdered ferro-boron. The holes were closed by stoppers made from iron of the same quality, these stoppers being pressed home by means of a hydraulic press. The powder being thus compressed, a good contact was secured between it and the sides of the sample, which was thus hermetically sealed. Specimens prepared by this method were heated in a Heraeus furnace in a silica tube. The temperature was measured by a Le Chatelier pyrometer, of which the thermo-junction was placed close to the specimen. In order to eliminate the influence of a gaseous medium, the whole of the air from the silica tube was removed by means of a mercury pump. The samples, after heating during several hours, showed no trace of oxide on the surface.

Fig. 1 (Plate VII.) shows two samples which were heated for two hours at 950°. Specimen I. contains amorphous boron, and Specimen II. powdered ferro-boron. Both samples were cut across longitudinally by means of a steel saw, and the cut surfaces polished.

At the lower part of the photograph are seen the stoppers, which are sometimes marked with thin bands, resulting from the contact with the cement powder left on their sides. The dark area over the stoppers represents the compressed cementing powder. The volumes of the compressed powders decrease partly on account of nodulising, partly owing to absorption by the sides of the specimens. The bands represent an alloy of iron with carbon, and can clearly be seen in the vicinity of the spaces containing the compressed boron or ferro-boron. Under the conditions of the experiment (950° and two hours' heating) the boron penetrated the iron to the depth of 1 millimetre.

From the experiment it was ascertained that cementation by powdered ferro-boron proceeds more easily and quickly than with amorphous boron. Microscopical examination shows that the hard white layer of the case-hardened part of the specimen consists of compact boric pearlite, with a twin crystal structure.

The photomicrograph of this portion is shown in Fig. 2 (Plate VII.). The edges of this layer contain a sub-eutectic alloy of ferrite-pearlite (see Fig. 3).

Magnified 350 diameters and reduced by three-elevenths.

FIG. 1.
Cubes of iron containing (I) amorphous boron, and (II) powdered ferro-boron.

FIG. 2.
Boric-pearlite with twin crystal structure.

FIG. 3.
Sub-eutectic alloy of ferrite-pearlite.

To face p. 186.

The ferrite in this instance contained the boron in hard solution, this being explained in the author's paper dealing with the diagram of iron-boron alloys previously referred to.

Case-hardening at a lower temperature yields an alloy of iron containing less boron. This alloy is not so hard and brittle as that already described. In order to render the process of case-hardening by boron suitable for industrial purposes, it would be necessary to carry out a series of experiments on the conditions most suitable to the particular purpose in view.

THE DETERMINATION OF THE LINE SE IN THE IRON-CARBON DIAGRAM BY ETCHING SECTIONS AT HIGH TEMPERATURES *IN VACUO*.

By Professor N. TSCHISCHEWSKY and N. SCHULGIN (Tomsk, Russia).

It has been shown, in a paper recently read before the Russian Metallurgical Society,[1] that the preheating of sections prepared from iron-carbon alloys, in a gaseous atmosphere, prior to etching by gaseous reagents, does not give satisfactory results because of the decarburising action of such gases as nitrogen, and in particular of hydrogen. The surfaces of such preheated sections not having the same composition as they possessed before preheating, will not, when etched, correspond with that point of the iron-carbon diagram corresponding to the carbon content of a given specimen. In order to remove all foreign influences it is necessary therefore to heat such sections *in vacuo*.

The best method of fixing the structure of a section at a high temperature would be to examine and photograph it directly at the required temperature. Unfortunately technical difficulties at present prevent this being done. In the investigation undertaken by the authors a sample of cement steel from the Urals containing 0·89 per cent. of carbon, 0·09 per cent. of silicon, 0·10 per cent. of manganese, 0·03 per cent. of phosphorus, and 0·02 per cent. of sulphur was taken, as well as a series of specimens of mild steel produced in a Tammann furnace in the author's laboratory, from soft Swedish nail iron containing 0·10 per cent. of carbon, 0·014 per cent. of silicon, 0·14 per cent. of manganese, 0·08 per cent. of phosphorus, and 0·0012 per cent. of sulphur, and a Swedish cast iron containing 3·96 per cent. of carbon and a very small proportion of other impurities such as 0·12 per cent. of silicon, 0·18 per cent. of manganese, 0·08 per cent. of sulphur, 0·02 per cent. of phosphorus, and 0·07 per cent. of copper.

[1] K. Krooglak, *Journal of the Russian Metallurgical Society*, 1915.

Preparation of the Specimens.

The Tammann furnace, which was of an improved form, was capable of melting 220 grammes of alloy, the melting being carried out in an unglazed porcelain tube closed at one end. A charge consisting of small pieces of wrought iron and cast iron was placed in the tube in alternating layers. When the furnace had been heated up beforehand, melting was effected in about twenty minutes. The charge was stirred several times and the tube returned to the furnace for another twenty to thirty minutes, after which the metal was poured into a mould. No visible oxidation occurred during fusion, as the furnace was covered with a bronze cylinder specially constructed and provided with a mica inspection hole, and a hole for the wire of the thermo-couple employed in obtaining the cooling curve of the alloy.

Three alloys were prepared, containing respectively 2·50, 1·505, and 1·25 per cent. of carbon. The cement steel and alloys were cut into discs and filed round, the ultimate area being about 0·5 cubic centimetre. The surface was rubbed smooth with emery paper and polished on a moistened cloth on which was spread alumina.

Arrangement of the Apparatus.

Chlorine was selected as the etching medium, because gaseous hydrochloric acid decarburises the steel by means of its dissociation products, *i.e.* the hydrogen. The chlorine was prepared by the action of strong hydrochloric acid on crystals of potassium permanganate, and was washed through water, sulphuric acid, and calcium chloride. During the etching the chlorine combines with the iron, forming anhydrous chlorides which volatilise at a comparatively low temperature, the volatilisation products condensing, in the form of red scales, on the cooler portions of the furnace.

The samples were heated in a Heraeus furnace (Fig. 1) provided with a glazed porcelain tube. One end of the tube projected about 50 centimetres from the furnace and was provided with a stopper having a hole through which a glass tube passed. This tube was provided with a tap *g* connecting the furnace

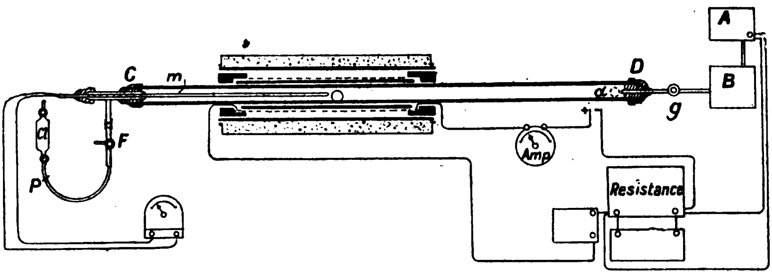


FIG. 1.—Heraeus Furnace with Porcelain Tube.

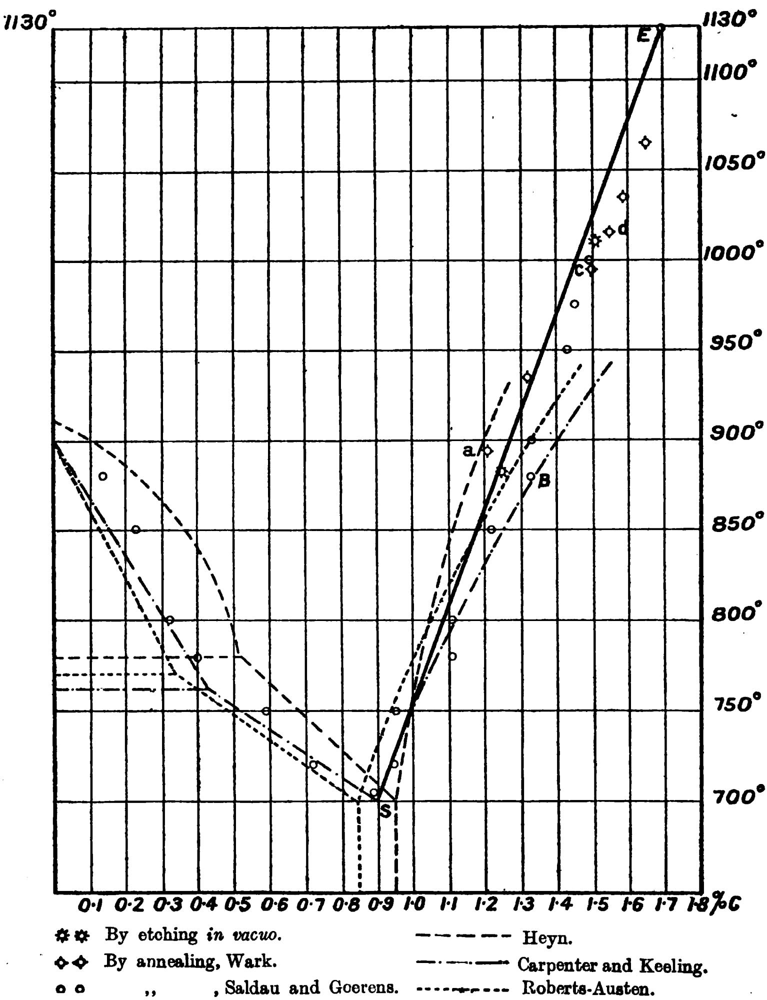


FIG. 2.—Determinations of Cementite Line by different Observers.

with a mercury pump B. The other end (C) of the tube was also provided with a perforated rubber stopper, through which passed a thin glazed porcelain tube *m*, 5 millimetres in diameter. This tube reached about the middle of the furnace and contained the thermo-junction of a Le Chatelier pyrometer. The end of the thermo-junction was connected with a Siemens-Halske millivoltmeter graduated for each 10° C. One end of the glass tube was connected with a tap F communicating either with the atmosphere or with a vessel filled with chlorine. A rubber tube between the tap and the vessel with a stopper *p* served to regulate the flow of chlorine required for etching. The pyrometer was standardised against gold and barium chloride.

The Mode of Operation.

At the cold end D of the porcelain tube was placed a polished section *a* of the sample. The tube was then closed with a rubber stopper and luted with Mendelejeff's mastic. By turning the tap K the furnace was connected with the mercury pump, and in fifteen minutes a vacuum of several thousandths of a millimetre of mercury was obtained. For checking the degree of vacuum a mercury manometer *m* was employed, and when a high vacuum was needed a Crookes tube was used, the required vacuum being attained when the yellow cathodal rays began to appear. The employment of the Crookes tube was the more convenient method, as it indicates continuously the maintenance of the vacuum without derangement of the apparatus, while with a McLeod vacuometer it is necessary at certain intervals systematically to test the vacuum.

When a sufficient vacuum has been obtained the furnace is disconnected by means of the tap K from the vacuum pump, the tap *g* being left open in order that the degree of vacuum may be ascertained. The furnace is heated and turned through an angle of 30° to 40° horizontally, whereupon the sample section rolls towards the central portion of the furnace until it reaches the porcelain tube containing the thermo-junction.

The furnace is then turned back to its original position and the sample kept at the requisite temperature for the requisite time.

PLATE VIII.

Magnified 600 diameters and reduced by one-ninth.

FIG. 3.—0·89% C., 635° C.

FIG. 4.—0·89% C., 695° C.

FIG. 5.—0·89% C., 750° C.

FIG. 6.—0·89% C., 750° C.

FIG. 7.—0·89% C., 780° C.

FIG. 8.—0·89% C., 905° C.

All sections etched by chlorine in vacuo at temperatures shown.

To face p. 192.

Magnified 600 diameters and reduced by one-ninth.

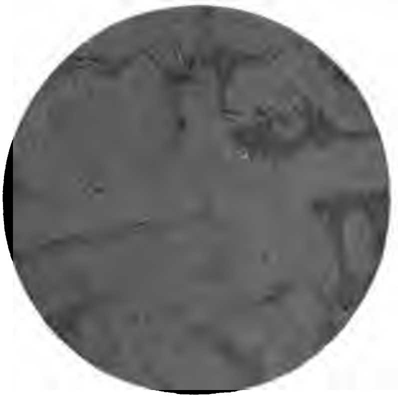


FIG. 9.—2·5% C., 650° C. Chlorine.

FIG. 10.—2·5% C., 925° C. Chlorine.

FIG. 11.—1·25% C. Picrate of sodium.

FIG. 12.—1·25% C., 875° C. Chlorine.

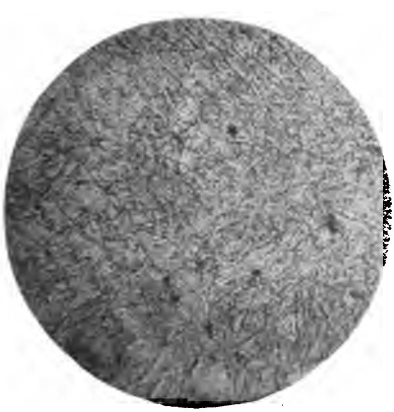


FIG. 13.—1·25% C., 890° C. Chlorine.

FIG. 14.—1·25% C. Picric acid.

Magnified 600 diameters and reduced by one-ninth.

FIG. 15.—1·25% C. Picrate of sodium.

FIG. 16.—1·25% C. Picrate of sodium.

FIG. 17.—1·505% C. Picrate of sodium.

FIG. 18.—1·505% C., 1005° C. Chlorine.

FIG. 19.—1·505% C., 1015° C. Chlorine.

FIG. 20.—1·505% C. Picric acid.

Magnified 600 diameters and reduced by one-ninth.

FIG. 21.—1·505% C.

FIG. 22.—1·505% C.

Both etched by picrate of sodium.

To face p. 193.

The mercury pump is then entirely disconnected by means of the tap *g*, in order to prevent the chlorine passing into it. A small amount of chlorine is allowed to flow into the furnace. After a few minutes the sample is rolled back to its previous position *a* by rotating the furnace, and cooled quickly at the end of the tube by means of cold water and snow. Air is then passed through, the stopper *d* opened, and the cold sample taken out for microscopical examinations.

A sample after etching by chlorine has a somewhat dull surface. With an excess of chlorine the surface becomes dark, due probably to the carbon. It having been noticed that samples in the open air were oxidised after a few minutes' exposure, the etched surface after removal from the furnace was covered by a thin layer of varnish, to protect it.

Preliminary Experiments.

In order to investigate the course of the etching by chlorine *in vacuo* the authors took two samples, one of cement steel containing 1·89 per cent. carbon, and the other an alloy produced in the Tammann furnace and containing 2·5 per cent. carbon.

The results of the etching of the cement steel were as follows: At a temperature below that at which the iron assumes the allotropic state γ, the etching shows a very distinct pearlitic structure, although a little coarser than is observed on etching with ordinary cold reagents. Fig. 3 (Plate VIII.) shows a section etched by chlorine at 635° C., and Fig. 4 one at 695° C.

Fig. 5 (Plate VIII.) shows a section etched at 715° C. This photomicrograph shows the presence of fine crystals which have had insufficient time to assume their normal structure—that is, a region of solid solution. Some crystals have a very clean surface, whilst others have a granular structure. In Fig. 6 the same specimen etched at 750° shows a polyhedric structure.

Figs. 7 and 8 (Plate VIII.) show the same steel etched by chlorine at temperatures of 780° and 905° C. respectively. The micrographs reveal polyhedrons having thin boundaries between the crystals.

The secondary structures martensite, troostite, osmondite, and sorbite were not observed in these experiments.

The influence of the temperature on the size of crystals is obvious. Their size increased with higher temperatures (Figs. 6, 7, 8; Plate VIII.).

The polyhedric structure observed during the etching by chlorine *in vacuo* shows very thin lines at the boundaries between the crystals as compared with those observed on etching with previous heating.

During the etching *in vacuo* by chlorine of a specimen containing 0·89 per cent. carbon, a pearlitic structure was found up to 695°, the polyhedric appearing at 715°. It may therefore be assumed that the pearlite line lies between 695° and 715° C.

A cooling curve obtained by the ordinary method shows an arrest at 702° C.

The other specimen, containing more carbon (namely 2·5 per cent.) and etched by chlorine with gradual increase of temperature, shows a decrease in the amount of cementite which was dissolved at the higher temperature.

Fig. 9 (Plate IX.) shows an alloy with 2·5 per cent. carbon etched by chlorine at 650°. The photograph shows a network of cementite and also cementite in thin plates. The dark spots represent oxide, and appeared when the specimen was exposed to air.

Fig. 10 (Plate IX.) is the same alloy etched by chlorine at 925°. The photomicrograph shows a solution of the thin crystals of the cementite and a thinning of its network. Between the network of the cementite may be observed a polyhedric structure representing the solid solution of carbon in iron.

The Determination of the Points on the Line SE.

The determination of the cementite line has been made by several authors, Roberts-Austen,[1] Heyn,[2] Carpenter and Keeling,[3] and more recently—by a method of annealing—by Wark,[4] and Saldau and Goerens.[5] The results of their work are shown in Fig. 2.

[1] Roberts-Austen, "Fifth Report of the Alloys Research Committee"; *Metallographie*, 1899, vol. ii. p. 186.
[2] Heyn, *Metallographische Untersuchungen von Eisenlegierungen, Verhandl. d. Ver. zur Beförd. d. Gewerbfl.*, 1904, p. 355.
[3] Carpenter and Keeling, *Journal of the Iron and Steel Institute*, 1904, No. I. p. 224.
[4] H. J. Wark, *Metallurgie*, 1911, p. 104.
[5] Saldau and Goerens, *Journal of the Russian Metallurgical Society*, 1914, p. 789.

There is some doubt as to the accuracy of the method of quenching, as the structure which is fixed after tempering can hardly correspond with the exact temperature of tempering. It must be borne in mind that a specimen cools in the air before being placed in water, while the water itself assumes the spheroidal state around a specimen, which further delays the conduction of heat. The result is that the point obtained by this method may be higher than it really should be.

The authors' experiments to determine the cementite line were based on the following considerations. During the heating of a sample above the pearlite line the cementite begins to dissolve and disappears entirely at the temperature corresponding with the points on the line SE. The specimens, which do not show the presence of cementite after the required heating and etching by chlorine, must therefore have been heated either very nearly to the line SE or somewhat above it.

Taking into consideration that specimens with a distinctly polyhedric structure nearly always suggest overheating above the line SE, it was decided to take an average between the two nearest temperatures, where one specimen shows a polyhedric structure and the other shows only traces of the cementite. To determine the points the authors took pieces of the alloy steel, mentioned above, polished them and heated them *in vacuo* at gradually increasing temperatures.

Before chlorine was passed, the samples were left in the furnace for half an hour or more. The difference of temperature during heating was not more than 2° to 3°, otherwise the experiment was repeated. A fresh specimen was always taken for etching, after which the sections were subjected to microscopical examinations. During an increase of the temperature there was noticed a distinct thinning of the crystals of the cementite, which afterwards disappeared. The intervals of the temperatures near the points were taken between 10° and 15°.

An alloy containing 1·25 per cent. carbon was first investigated. Fig. 11 (Plate IX.) represents this alloy, etched by picrate of sodium. The cementite here was crystallised mostly as needle-like crystals.

Fig. 12 shows the same alloy, which was heated in the furnace at 875° and etched by chlorine. From this photomicrograph

can be seen the needle-like crystals of cementite, which become thinner than in the previous case, and are enclosed in a polyhedric matrix of dissolved pearlite.

Fig. 13 shows the same alloy, containing 1·25 per cent. carbon etched by chlorine at 890°. The photograph shows the polyhedric structure. In this instance all the cementite was transformed into solid solution.

Photographs 12 and 13 show therefore that the cementite line passes between 875° and 890° C. when the carbon percentage corresponds with 1·25 per cent.

As a boundary of the presence of cementite in this interval the point corresponding with the average between these temperatures, namely 883°, has been assumed (see Fig. 2).

In regard to the determination of the other point of the line SE, the authors took a sample containing 1·505 per cent. carbon.

Fig. 17 (Plate X.) shows its microstructure after etching by picrate of sodium. The greater part of the cementite here forms needle-like crystals, and only a small amount forms a net located near the boundaries of the crystals.

Fig. 18 shows the same alloy, etched by chlorine at 1005°. Here it is seen that the needles of the cementite have not yet been dissolved and only become thinner in comparison with those of the previous example.

Fig. 19 shows the same alloy etched by chlorine at 1015° C. The photograph shows the formation of the polyhedric structure. All the cementite is transformed into solid solution.

From photomicrographs 18 and 19 it may be seen that the point of the line SE must be between 1005° and 1015°, the average 1010° C. being taken as correct.

From the specimens shown at Figs. 12 and 13 and Figs. 18 and 19 were filed off layers about 1 millimetre in thickness. The surfaces were polished and etched by picric acid and picrate of sodium. It was discovered that the cementite of the samples, shown in Figs. 12 and 18, forms a network and several needle-like crystals.

Samples 13 and 19, which are beyond the line SE, contain the cementite in the form of a network. Evidently all the needle-like crystals of the cementite were dissolved and there were no

traces of them as centres of crystallisation, but all the cementite occurred as a network near the boundaries of the crystals.

Figs. 14 and 20 are photographs of a filed specimen, shown in Figs. 12 and 18, and etched by picric acid. Here the cementite appears in the form of network of white needle-like crystals. Figs. 15 and 21 show the same specimens etched by picrate of sodium. The cementite here is coloured.

Figs. 16 and 22, which are, on the other hand, photographs of specimens heated above the line SE, show only a network of cementite near the boundary of the crystals.

They correspond with photographs 13 and 19, prepared after etching by chlorine.

The results of the investigation are shown in the following table:

No. of Sections.	Per Cent. Carbon.	Temperature.	Etching Medium.	Magnification.	Structure.	Remarks.
3	0·89	635	Chlorine	600	Striped pearlite	Cement steel.
4	,,	695	,,	600	Pearlite	,, ,,
5	,,	715	,,	360	Polyhedric	Fine crystals having no time to form.
6	,,	750	,,	370	,,	Size of crystals increase.
7	,,	780	,,	370	,,	
8	,,	905	,,	370	,,	
9	2·5	650	,,	370	Cementite	Cast steel. The dark spots are oxides.
10	,,	925	,,	370	Cementite and austenite	Thinning of cementite.
11	1·25	,,	Picrate of sodium	370	Needle-like crystals of cementite	Cast specimen not annealed.
12	,,	875	Chlorine	370	,,	Needle-like crystals of cementite become thinner.
13	,,	890	,,	370	Polyhedric	Complete solution of needle-like crystals of cementite.
14	,,	,,	Picric acid	370	Cementite	After filing off a layer from specimens 13 and 14.
15	,,	,,	Picrate of sodium	370	,,	
16	,,	,,	,,	370	,,	
17	1·505	,,	,,	370	,,	Cast specimen not annealed.
18	,,	1005	Chlorine	80	,,	Thinning of needle-like crystals of cementite.
19	,,	1015	,,	370	Polyhedric	Complete solution of needle-like crystals of cementite.
20	,,	,,	Picric acid	370	Cementite	After filing off a layer from specimens 19 and 20 of 1 millimetre.
21	,,	,,	Picrate of sodium	370	,,	
22	,,	,,	,,	370	,,	

Assuming as a maximum limit of the saturation of iron by the cementite the point corresponding with 1·7 per cent. carbon and 1130° C. and as the eutectoid point 0·9 per cent. carbon and 700° C., and connecting them by a straight line, it is found that the points corresponding with the end of dissolution and the beginning of the appearance of the cementite are near this line. The point corresponding with 1·25 per cent. carbon and 883° C. is a little below the line, almost at the same distance from the points *a* of H. Wark and from the point *b* of Saldau and Goerens in the direction of a perpendicular to the line SE. The second point, corresponding with 1·505 per cent. carbon and 1010° C., lies a little further from this and is placed with regard to the nearest points *d* (Wark) and *c* (Saldau and Goerens) in a reverse relation, that is, it is at the same distance as the point of Saldau and Goerens, but nearer than Wark's point.

The proximity of these points to the straight line, between the points S and E, justifies the supposition that the line ES is a straight line.

CORRESPONDENCE.

Professor H. C. H. CARPENTER (Royal School of Mines) wrote expressing his interest in the paper by Professor Tschischewsky and Mr. Schulgin, and to point out that their conclusion that the line SE, representing the separation of cementite from solutions of austenite, whose carbon content varied from 0·90 to 1·70 per cent., was "straight," agreed with that reached by Mr. Keeling and himself in 1904. They then stated [1] (p. 239): "The initial formation of cementite from the homogeneous solid solution of carbon in iron, *i.e.* for carbon percentages between 0·9 and 1·7, may be represented quite as well by a straight line as by the curve given by Roberts-Austen and Hadfield (Plate V., Fifth Alloys Research Report)." The conclusion was emphasised in item 4 of their summary (p. 242) in the words: "SE may be represented quite as well by a straight line as by a curve."

The method adopted by Messrs. Tschischewsky and Schulgin to determine the course of the line SE was one of considerable interest, involving as it did the use of chlorine as the etching reagent. He would like to ask the authors to explain why the specimen containing 2·5 per cent. of carbon etched at 650° C. with chlorine (Fig. 9, Plate IX.) did not show a pearlitic structure. Was not this to be expected?

Dr. H. M. HOWE, Hon. Vice-President, wrote: This determination of the position of SE is extremely welcome as confirming the previous ones approximately, by a wholly independent method. The experimental arrangements seem very ingeniously and intelligently devised.

The authors might well have added to their interesting Fig. 2 the results of Gutowsky,[2] which certainly deserve very great weight. They lie materially above the line SE as the authors have drawn it.

The authors' objection to the quenching method seems to me overstated. It is true that in this method a certain brief time must elapse between the instant when the specimen leaves the temperature of the individual experiment, and that of its arrival at a temperature so low as to arrest completely the migration of any cementite precipitated in this time. But I doubt whether any cementite which precipitates during this very brief interval can coalesce into particles large enough to be detected under the microscope, and it is only by such coalescence into visibility that such precipitation can vitiate the results of the quenching method.[3] It is also true that any such coalescence would

[1] *Journal of the Iron and Steel Institute*, 1904, No. I. pp. 224–242.

[2] *Metallurgie*, 1909, vol. vi. p. 731.

[3] Mr. Levy and I found that no ferrite thus coalesced into visibility, in steel of 0·40 per cent. of carbon, in four minutes at 737° followed by quenching, though on longer holding at even higher temperatures the ferrite formed visible masses. In steel of 1·14 per cent. of carbon only extremely small quantities of pro-eutectoid cementite in isolated fragments of network coalesced into visibility during four minutes at 799° followed by quenching, though on 36, 108, and 216 minute exposures to 793°–803° followed by quenching an abundant net-work formed.

tend to place the observed position of SE above its true position. On the other hand, the quenching method has in common with the authors' a tendency to depress the apparent position of SE. Each of these methods determines not the true completion of the absorption of the pro-eutectoid cementite on heating, and the true beginning of its precipitation on cooling, but the reduction of that cementite to undetectably small masses in heating, and its coalescence into detectably large masses in cooling. Here the quenching method probably has a distinct advantage over the authors', which may equal if it does not exceed any possible disadvantage due to the coalescence of cementite during the quenching, the advantage of the opportunity to repeat the etching on any given specimen as many times as we wish, whereas the chlorine etching has to be done once for all. We may suspect that the indications given by the cold etching of the quenched specimen, as to the presence or absence of cementite islets, are sharper than those given by the chlorine etching, and hence that the error through failure to detect the last of the disappearing cementite in heating, and the first of it in cooling, is less with the quenching than with the chlorine method. It is in accordance with this thought that the authors' position of SE is decidedly below that of Gutowsky.

The determination of only two points on SE, however welcome should be taken only as a step towards its full determination.

The authors' observation on p. 197 that the pro-eutectoid cementite in their specimens of hyper-eutectoid steel with 1·25 and 1·505 per cent. of carbon which have been heated above SE exists only in the form of a network and does not form independent needles within the meshes of that network cannot be taken as a general law, for Mr. Levy and I[1] showed the abundant precipitation of these internal needles in steel of 1·45 per cent. of carbon cooled from 1200° to various points within the transformation range and then quenched.

Dr. McCance (Glasgow) wrote that the authors were to be congratulated on the care with which their apparatus had been built up so as to avoid the errors which could and did vitiate the results of etching experiments at high temperatures. In avoiding these errors they seemed to have been successful, but it was a matter for regret that a larger number of specimens covering a wider range in composition were not examined, since they could scarcely claim to be able to fix such an important line on the iron-carbon diagram by means of two points only. For the view that the corresponding saturation limit of a steel containing 1·7 per cent. of carbon occurred at 1130° C. was an assumption open to doubt, and a doubt which had not been removed by the results of the present investigation. Indeed the agreement between the values obtained by the authors and those previously published was so close that he (Dr. McCance) thought the general

[1] Howe and Levy, "The Life History of Pro-eutectoid Cementite," *Proceedings of the Sixth Congress of the International Association for Testing Materials*, 1912, II_4, Plate I.

verdict would be that until a more extensive investigation was undertaken, there was little reason for altering the position of the line SE as given by Wark up to 1·6 per cent. carbon.

Above that concentration, however, there was a real necessity for an accurate and close investigation as a means not only of fixing the line SE, but also of determining the point E which gave the maximum saturation limit for carbon of gamma-iron. He hoped that the authors would see their way to undertake such further work, as it had an important bearing on the theory of the iron-carbon diagram, and the results from their hands would be valuable.

AN ELECTRO-MAGNETIC METHOD FOR DETERMINING THE CRITICAL POINT IN THE HEAT TREATMENT OF STEEL.

By R. B. FEHR, Assist. Prof. Mech. Eng. (The Pennsylvania State College, U.S.A.).

INTRODUCTION.

At the suggestion of Sir Robert A. Hadfield, F.R.S., the writer has the honour to submit the following article on the development of a new method for determining the critical point in the heat treatment of steel. In presenting this paper he is conscious of the fact that he has nothing to add to the controversy regarding the allotropy of iron and the theories of the hardening of steel, but he trusts that it may be of some interest if he describe a new application of some fundamental physical laws to the heat treatment of steel.

The work was performed during the winter of 1911–12. For several years the writer had been interested in the study of the heat treatment of steel from both theoretical and practical sides. In spite of the great advances that had been made in the past twenty years, there appeared to be considerable room for improvement, especially in the way of making a more scientific application of well-established principles to commercial heat treatment. In particular, there seemed to be too much vagueness in regard to the proper temperature for annealing or hardening. Although the many practical and scientific writers on this subject agreed that the heat-treating operations should take place just above the "decalescent point" (*i.e.* above the line GOSK, Fig. 1) in order to obtain maximum refinement of grain, a considerable latitude was allowed when it came to recommending actual temperatures. For instance, the proper annealing temperatures for carbon steels are stated as lying between 790° C. and 925° C., depending on the carbon and, to a less extent, on the manganese content, and also on the size of the piece. As

Ac3.2.1 for eutectoid steel (0·85 per cent. carbon) is usually less than 760° C., it is obvious that in the most favourable case the

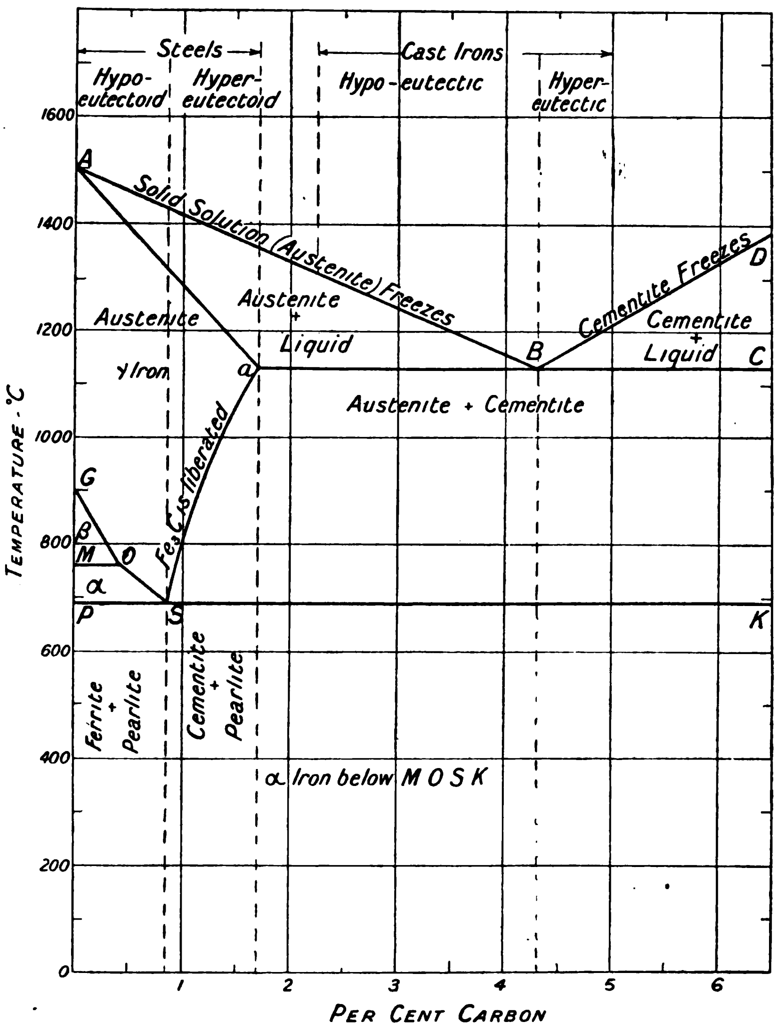


FIG. 1.—Iron-Carbon Equilibrium Diagram.

steel must be heated at least 30° C. above the decalescent point, if the recommendations are followed. But this is not all. The

pyrometer that is used in the shop is not the one that is used in determining the critical point of the steel sample in the laboratory, nor are the conditions of heating the same in both cases. Furthermore, heat-treating furnaces are not usually controlled within less than 10° C. By the time the errors due to the calibration of pyrometers and variations in the temperature and conditions

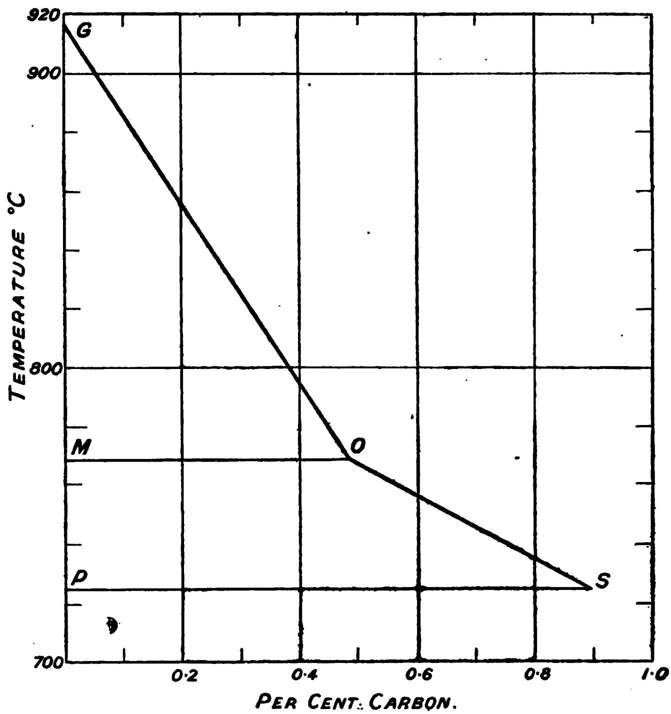


FIG. 1A.—Part of FeC Diagram.

of heating have been added to the above 30°, it is very evident that the actual heat-treating temperature may often be 50° C. or more above the critical (decalescent) point.

Moreover, when it was recalled that careful experiments had proved that a variation of a few degrees, from below to above the critical point, would produce vast changes in the physical properties of steels, it became very evident that the "critical range" in heat treatment offered a fruitful field for

further study and research.[1] In the writer's opinion the first thing to do was to improve upon the method of determining the proper temperature for heat-treating. It was obvious that a direct method of determining this important point in the piece of steel actually undergoing heat treatment would be far superior to the present one, which involved so many factors. With this end in view the writer entered upon a research in which he evolved an electro-magnetic method for directly determining the critical point.[2]

Requirements for Successful Heat Treatment.

The chief requisites for obtaining the most successful results in practical heat-treating operations may be summarised as follows:

1. The furnace should be controlled within 10° C.
2. The temperature should be uniform.
3. The critical temperature should be directly determined on the piece of steel undergoing heat treatment.
4. The apparatus for this determination should be simple and sensitive, and should be located at some point outside of the furnace where it is not exposed to intense heat.

This research was concerned with the last two requisites, and therefore a study was first made of the critical temperature or rather range of temperature.

The Critical Range of Temperature.

In the iron-carbon equilibrium diagram (Fig. 1) the temperatures between GOS*a* and PSK are said to lie in the "critical range." Within this range of temperature occur many striking changes in such physical properties as magnetic permeability, crystalline structure, dilatation, electrical conductivity, thermal conductivity, specific heat, and thermo-electric power. The thermal effects of these changes, as manifested by the thermal critical points, have been made use of to the greatest extent

[1] The paper (*Journal of the Iron and Steel Institute*, 1913, No. II. p. 399) by Dr. Stead (subsequent to the time of this research), in which he tells of submitting samples of 0·9 per cent carbon steel (cut from the same bar) to sixteen reliable investigators, who returned results for Ac3.2.1 ranging from 719° C. to 746° C., furnishes an interesting commentary on the futility of attempting to lay down any definite range of temperature as *the* range in which to heat-treat a certain kind of steel.

[2] U.S. Patent, Nos. 1, 188, 430.

but do not readily permit of direct determination in the piece of steel undergoing heat treatment.

The Magnetic Critical Point.

Of the other changes, those in the magnetic permeability offered the best possibilities for application to practical heat-treating operations. In the first place, the experiments of Hopkinson, Curie, Morris, Osmond, and others show that the magnetic permeability of steel falls abruptly to almost unity when the temperature reaches the line MOSK. In the second place, this magnetic critical point coincides, in the case of practically all the carbon steels that are given heat treatment (0·5 to 1·20 per cent. carbon), with that thermal critical point just above which steel should be heated to obtain the minimum size of grain. In the case of steels below 0·4 per cent. carbon the proper annealing temperature, which falls on the line GO, can be readily judged by the eye or determined by the pyrometer after establishing the magnetic critical point on the line MO. Furthermore, low carbon steels are relatively unimportant from the standpoint of heat treatment, and are very little affected throughout a comparatively wide range of temperature. In theory, then, the magnetic critical point (occurring along MOSK) seems to be the correct heat-treating temperature.

On the practical side it is interesting to note that the technical press has mentioned the use of the magnet [1] and the magnetic dipping needle in connection with the hardening of tools. In this case either the magnet must occasionally be introduced into the furnace, or the steel must be withdrawn. The method is therefore inconvenient and open to the further objection that the magnetic indicator is likely to be influenced by the proximity of other iron bodies. Descriptions [2] have appeared of furnaces equipped with a magnet holding the steel, which, after becoming non-magnetic, drops into the quenching bath. The principal objection to this arrangement is the fact that the loss of magnetic properties can occur only gradually, and the magnetic attraction

[1] *Machinery*, April 1908. See also "The Metallurgy of Iron and Steel," by Bradley Stoughton, p. 389 (1st edition).
[2] "The Composition and Heat Treatment of Steel," by E. F. Lake, p. 182.

between the magnet and the steel may become so small that the piece may drop into the bath before it becomes entirely non-magnetic and ready for quenching. On account of these mechanical difficulties practical men have had a prejudice against the magnetic determination of the critical point. However, the methods just referred to clearly violate the fourth requisite for practical heat treatment as set forth on page 206, and with this point kept constantly in mind the author proceeded to consider the possibilities of electromagnetism rather than magnetism alone.

FUNDAMENTAL PRINCIPLES.

Oersted in 1820 discovered that a wire carrying an electric current was surrounded by a magnetic field, and in 1825 Sturgeon produced the first electromagnet, but it remained for Faraday to discover in 1831 the important principle of induced electric currents, which has been employed in the present research. Moreover, the loss of magnetic properties in iron when heated to bright redness has been known from the time of Gilbert (1540–1603). Concisely expressed these principles are as follows:

1. Steel loses its ferromagnetism at its Ac2 point (line MOSK), but recovers this property on cooling past Ar2.
2. An electric current can be induced around a closed circuit by changing the magnetic flux through any part of it, the magnitude of the induced current being proportional to the rate of change of magnetic flux.

PRELIMINARY EXPERIMENTS WITH AIR GAP.

The loss of magnetic properties in steel that forms part of a magnetic circuit is equivalent to the introduction of an air gap, for the permeability of all non-magnetic substances is practically unity. It was therefore evident that any new arrangement, based on the above principles, for determining the critical point, could be tested out in a preliminary way without heating the steel, for the introduction of an air gap would be the equivalent of the heating of the test-bar past the magnetic critical point

Ac2. Accordingly, the apparatus shown in Fig. 2 was set up,

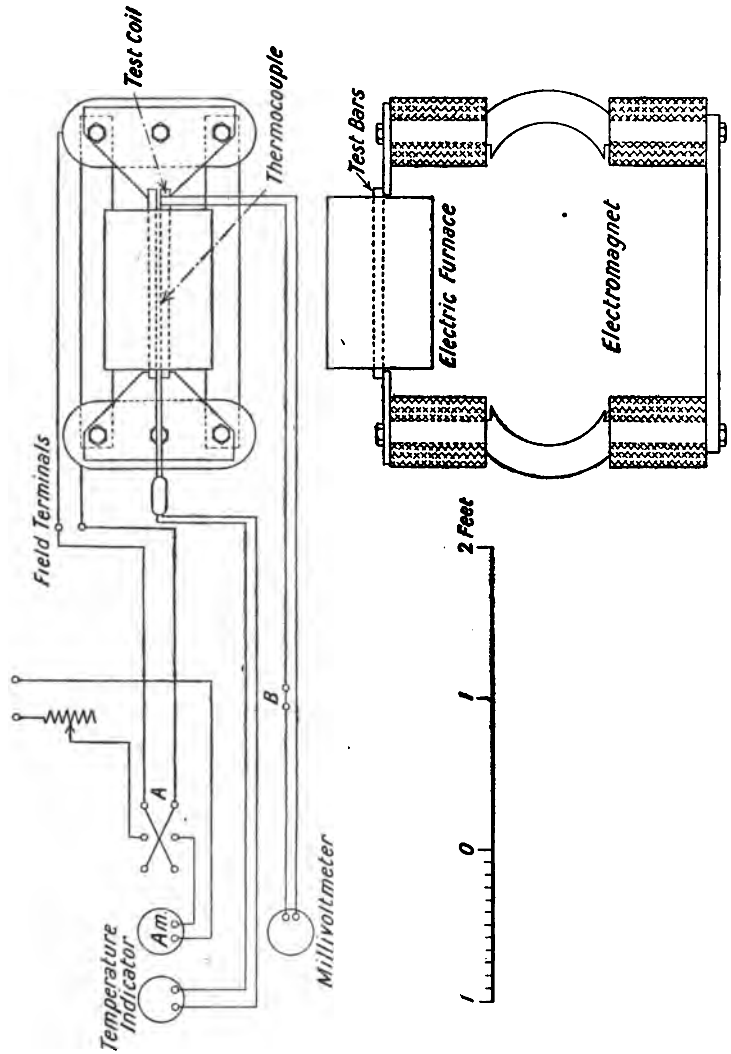


Fig. 2.—Diagram of Connections.

but the furnace and pyrometer were omitted in the first experiments.

In a contemporary research[1] to determine the combined effect of magnetic flux and various annealing temperatures on the physical properties of carbon steels, a strong magnetic flux had been provided by an old type, series-wound generator. The end yokes had been removed, and the field coils spread apart about 24 inches. These were connected at the bottom by six strips of wrought iron (each having a cross section of 2½ inches by ½ inch), while the upper part was left open to admit the test-pieces and small electric furnace.

Two pieces of 0·04 per cent. carbon steel ¾ inch-round bars were cut to lengths of 6½ and 8½ inches, the ends being carefully trued up. These rods were placed end to end on wooden guides between two cast iron plates, which were bolted to the magnet cores. Each rod was in contact with its pole piece for a distance of ½ inch. A test coil consisting of twenty turns of No. 18 copper wire was slipped over the 6½-inch rod next to the pole piece and was connected to a millivoltmeter reading up to 100 millivolts. In order to fulfil the condition of a changing magnetic flux without moving the coil, a double-pole, double-throw switch was inserted in the primary or field circuit.

With this arrangement of apparatus the following experiment was performed. Switch A was closed to the right and the current through the field coils adjusted to a certain value (16 amperes in the first case). The circuit was then broken by means of switch A. The consequent collapse of the magnetic lines of force (equivalent to a change in magnetic flux) caused a momentary induced current in the secondary or test coil circuit, with the result that there was a momentary deflection, ϕ_b, of the millivoltmeter pointer. After this reading had been noted, switch A was closed to the left so as to reverse the field current. This building up of magnetic flux by current passing in the opposite direction caused the secondary current to move in the same direction as when the switch was opened. This deflection, ϕ_m, on making the circuit was also noted. In the absence of a zero-centre millivoltmeter it was necessary to open the single throw switch, S, in the secondary circuit before opening switch

[1] "The Annealing of Carbon Steels as Affected by Various Temperatures and Magnetic Flux," Bulletin No. 18, Engineering Experiment Station of the Pennsylvania State College. An abstract of this article appeared in the *Journal of the American Society of Mechanical Engineers*, January 1917, p. 82.

A and closing it to the right, for in these cases the induced current, being in the opposite direction, might have injured the pointer. Of course, a reversing switch might have been used in the secondary circuit, but the set of two readings thus obtained would have been a duplicate of the first set.

For the next set of two readings a piece of paper (about 0·005 inch thick) was inserted between the ends of the two bars. A slight change in the deflections was noted. Then various wooden spacers were placed between the test-bars so as to increase the air gap. The bar through the test coil was not disturbed but the other bar was moved, thus acquiring a larger contact with its pole piece.

The results, shown in Table I. and Fig. 3, were very interesting and encouraging. The deflections, ϕ_b, caused by breaking the

TABLE I.—*Results of Air Gap Experiment.*

Width. Air Gap. Inches.	Field Current.	ϕ_b (break).	ϕ_m (make).	$(\phi_b + \phi_m)$.
0	16·0	26·8	59·0	85·8
0·005	16·0	27·9	58·0	85·9
0·10	16·0	33·0	51·0	84·0
1·00	16.0	35·2	48·0	83·2
3·00	16·0	36·0	46·2	82·2
8·00	16·0	36·2	45·7	81·9
0	1·0	8·3	15·5	23·8
0·005	,,	8·0	14·5	22·5
0·10	,,	6·5	10·0	16·5
0·50	,,	5·2	8·0	13·2
1·00	,,	5·2	7·5	12·7
3·00	,,	5·0	7·0	12·0
8·00	,,	4·8	6·5	11·3

circuit, increased abruptly when the test-bars were separated by an air gap, while the deflections, ϕ_m, on making the circuit decreased abruptly. There was, however, only a comparatively gradual change in the sum of the deflections. Subsequent experiments showed that this calculated sum $(\phi+\phi_m)$ was practically the same as that obtained directly by reversing the switch A very suddenly. It is interesting to note that this quantity $(\phi_b+\phi_m)$ corresponded to the readings obtained by the method of reversals and ballistic galvanometer as employed

by investigators on the magnetic properties of steel at high temperatures, but, of course, for practical heat-treating operations this latter method was obviously impracticable.

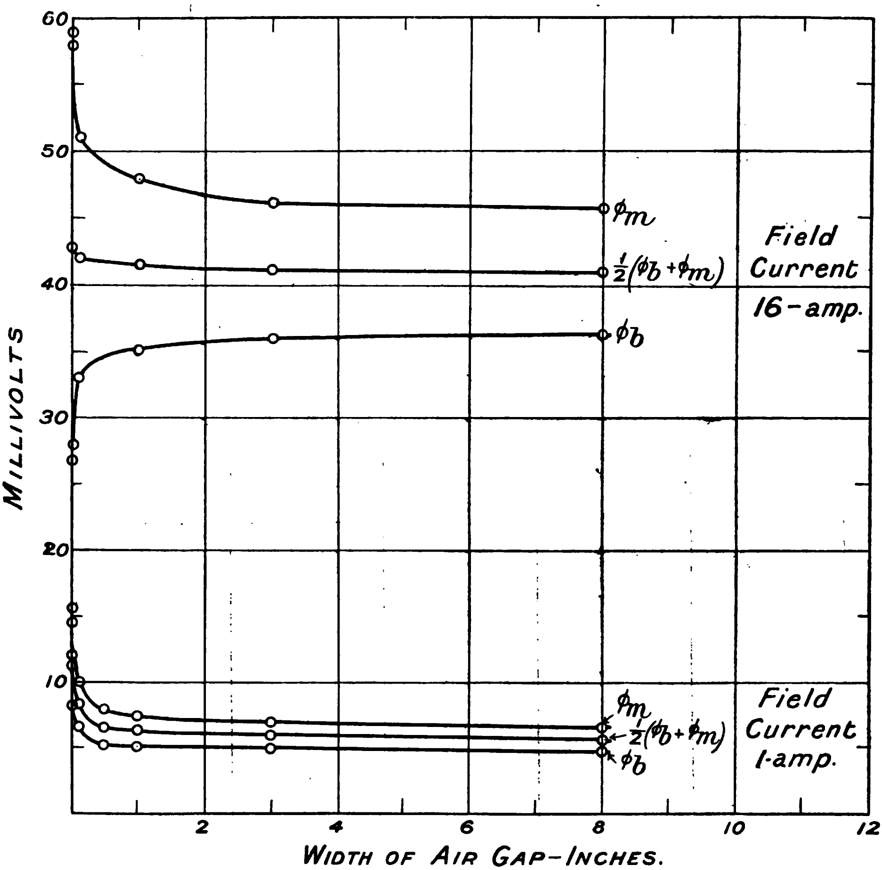


FIG. 3.—Effect of Air Gap.

The increase of the readings, ϕ_b, caused a little surprise at first, but a study of the peculiarities of the magnetic circuit cleared up this point. In this connection magnetisation curves were obtained of several steel bars ($\frac{3}{4}$ inch in diameter by 15 inches long) laid across the pole piece with the test coil at one end. The field current was varied from 0 to 50 amperes, the

deflections at the make and break of the primary circuit being noted for each value of the current. The results were plotted in Fig. 4, where the abscissæ are proportional to the magnetising force, and the ordinates to the total induction through the test coil as given by the quantity $\frac{1}{2}(\phi_b+\phi_m)$. A field current of 16 amperes was thus found to give a magnetic induction considerably above the knee of the magnetisation curve. Let us assume that the total magnetic induction, B, due to 16 amperes of field current, was 15,000 units. Breaking the field circuit caused this flux to drop to a residual flux value, Br, of, say, 5000 units, with the resulting millivoltmeter deflection, ϕ_b, corresponding to the change in flux, 15,000 − 5000 = 10,000 units. Making the circuit

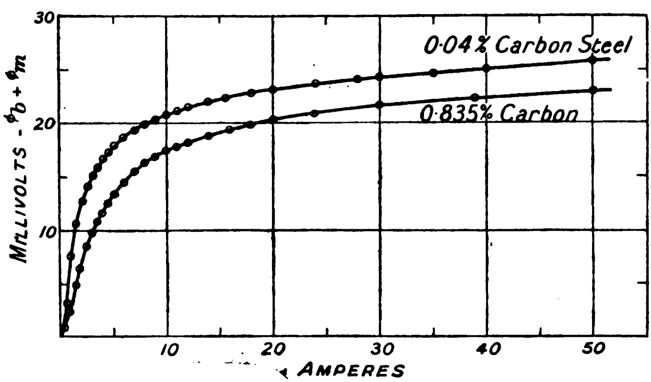


FIG. 4.—Magnetisation Curves.

in the opposite direction caused the flux to change from 5000 to − 15,000 units. This total change of 20,000 units therefore gave a deflection ϕ_m double that of ϕ_b. When a 1·00 inch air gap was introduced, ϕ_b increased abruptly about 30 per cent. This meant that the above difference of 10,000 units was increased to 13,000. The quantity $\frac{1}{2}(\phi_b+\phi_m)$ decreased only about 3 per cent., showing, as was to be expected, that the introduction of an air gap did not materially affect the total induction of a steel bar that is magnetised beyond its saturation point. Suppose that the total induction with 1·00 inch air gap was 14,500 instead of 15,000 without the air gap. Then 14,500 − 13,000= 1500 units, the residual magnetism, Br. The deflection, ϕ_r,

which was about 20 per cent. less than ϕ_m with no air gap, was obtained by the change of flux from $+1500$ to $-14{,}500$, or 16,000 units, 20 per cent. less than the previous change of 20,000 units.[1] It was thus noted that the introduction of an air gap caused the magnetic induction to decrease very slightly in comparison with the decrease in residual magnetism. Further reflection showed that this condition was to have been expected, for the two poles produced by an air gap cause a self-demagnetising force, which decreases considerably the residual magnetism. These considerations seemed to explain satisfactorily the reason why the deflections, ϕ_b, increased, rather than decreased, as would have been expected on first thought.

This experiment on the effect of air gaps was repeated with the field current adjusted to 1 ampere, which, from the magnetisation curve of Fig. 4, gave a magnetic induction considerably below the saturation point. In this case there were abrupt decreases in all these quantities, ϕ_b, ϕ_m, and $\frac{1}{2}(\phi_b+\phi_m)$, the decrease in ϕ_b indicating that the total induction, B, is affected more than the residual magnetism, Br, by air gaps when steel is magnetised below its point of saturation. A study of Figs. 3 and 4 would lead one to expect that for a certain magnetising current, probably that corresponding to the knee of the magnetisation curve, there would be no appreciable change in the deflections, ϕ_b, but that the deflections, ϕ_m, would always change when an air gap or its equivalent was introduced. These and other points might be of theoretical interest to investigate, but for the practical purpose of developing a method to be used in heat treatment, the author considered that these preliminary experiments justified the application of the method to heating furnaces.

Electric Furnaces.

On account of its ease of temperature control and general simplicity, the wire-wound resistance type of electric tube furnace was employed for the following experiments. The alundum tube had a length of 12 inches and an internal diameter of 2 inches, and was wound with 22 turns (11 in one direction, and 11 in the opposite direction to neutralise the magnetic field) of

[1] To be exact these values of magnetic flux should have been made proportional to the millivoltmeter readings in Table I., but for purposes of explanation round numbers were taken.

0·014 inch by 0·125 inch nichrome resistance ribbon. In order to obtain a fairly uniform temperature for several inches along the middle of the tube, the windings were spaced more closely at the ends than in the middle. The tube was placed in an asbestos wood box and surrounded by quartz sand. As thus constructed the furnace consumed about 20 amperes at 110 volts, and with proper control of the rheostat gave a constant temperature, within 10° C., for about 4 inches along the middle length of the tube.

Measurement of Temperature.

Inasmuch as these experiments were concerned primarily with the magnetic critical point and not with the thermal critical points, no elaborate system of pyrometry was set up. As a basis of reference, however, several thermocouples were employed, millivoltmeters being used as indicators. Temperatures up to 950° C. were measured by an "Advance" (iron-constantan) pyrometer in which the iron casing ($\frac{1}{2}$ inch in diameter and 30 inches long) served as one element of the couple. Above 950° C. a platinum platinum-rhodium couple with porcelain protecting tube was used. A similar but bare platinum couple was used in obtaining the decalescent and recalescent points of a sample of the steel.

In order that these three couples might serve as a true basis of reference, they were carefully compared with each other, the enclosed platinum couple, which had been recently calibrated against a standard, being used as the secondary standard in this work. Frequent comparison of these couples (always under the working conditions of their use) failed to reveal any considerable variations. It is altogether probable that the observed temperatures were within 10° C. of their absolute value.

Application of Electromagnetic Method to Electric Furnace.

With the apparatus shown in Fig. 2 a number of experiments were run on $\frac{1}{2}$ and $\frac{3}{4}$ inch bars ranging from wrought iron to 0·9 per cent. carbon steel. On account of the conduction of heat along the test-bar, the test coil was made of enamelled copper wire wound on an asbestos wood spool. The method of taking

readings was the same as that for the air gap experiment except that observations of temperature took the place of the widths of air gap.

RESULTS.

All of these experiments gave results that were similar to those obtained in the air gap experiments. The curves[1] of Fig. 5 are typical for eutectoid steel when the rate of heating past the critical point is very slow—in this case, 0·87° and 0·56° per minute in passing from 740° C. to 760° C. for the field currents of 16 amperes and 1·0 ampere, respectively. When the steel was heated at the normal rate of the furnace, and no attempt was made to hold the temperature at the critical point, the magnetic critical points were not so sharply indicated as shown in the curves of Fig. 6, in which case the rate of heating from 740° to 760° C. was 15·0° per minute.

In all cases it was noted that the magnetic transformation of the test-bar required an appreciable length of time, for the very simple reason that all parts could not be heated past the critical point simultaneously. Comparing the curves of Fig. 5 (for slow heating) with the air gap curves of Fig. 3, one must conclude that their similar characteristics are due to the fact that the millivoltmeter deflections depend primarily upon the length of air gap or its equivalent (*i.e.* steel heated past its critical point) and upon the time and temperature only in so far as these factors cause a greater length of the bar to become non-magnetic. The less abrupt indication of the magnetic critical point in Fig. 6 is therefore due merely to the manner of plotting. If the *lengths* of the non-magnetic part of the bar had been determined by an elaborate system of pyrometers, and these lengths had been plotted instead of the temperatures, as obtained in the hottest part of the furnace, it is very probable that these critical point curves would have been similar to those in Figs. 3 and 5.

The results obtained with other kinds of steel were similar, in the main, to those just described, but in the case of the very low carbon steels there was little hysteresis (see sample G, 0·04 per cent. carbon, in Fig. 7). By this term " lag " is meant, that is the critical point as at the lower temperature on cooling this steel.

[1] In Figs. 5 and 6 the small solid circles denote points on heating, while the large open circles denote points on cooling.

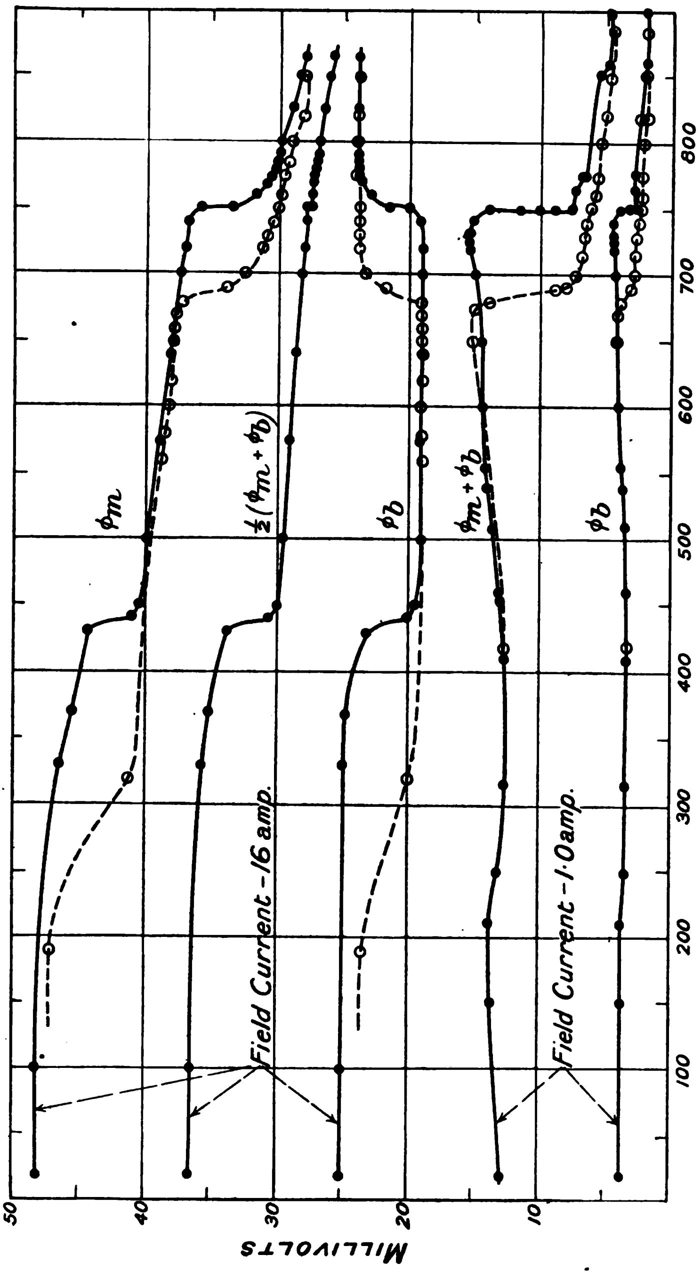


FIG. 5.—Magnetic Critical Point. Slow Heating. 0·835 per cent. Carbon Steel (¾ in. dia. × 15 in. long).

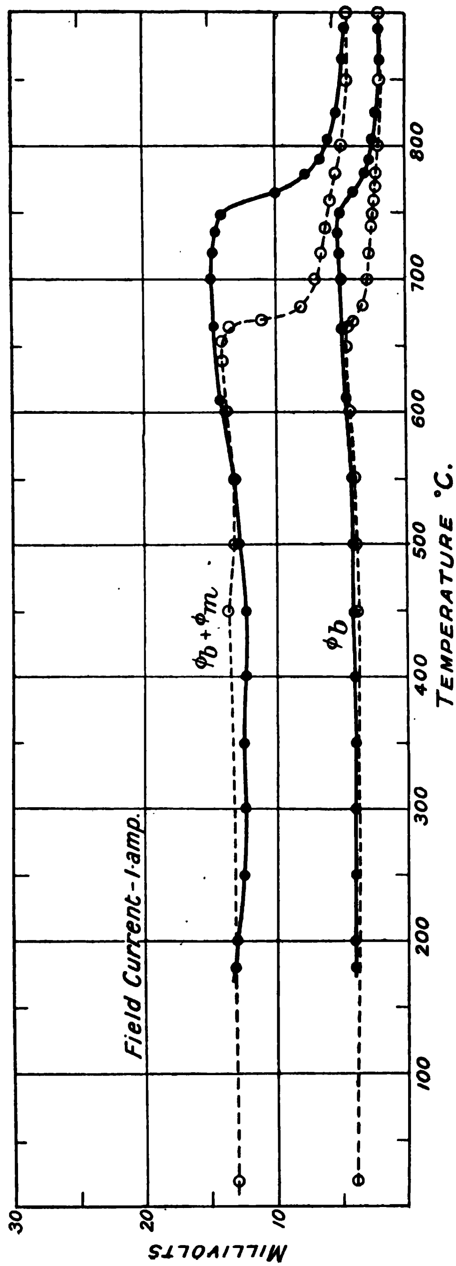


FIG. 6.—Magnetic Critical Point. Rapid Heating. 0·835 per cent. Carbon Steel.

Application to 30-Inch by 3-Inch Electric Furnace.

It might be of interest at this point to make mention of a subsequent application of this electromagnetic method to a larger experimental electric furnace that had been built at some previous time. This furnace had a 30-inch by 3-inch tube, and was wound

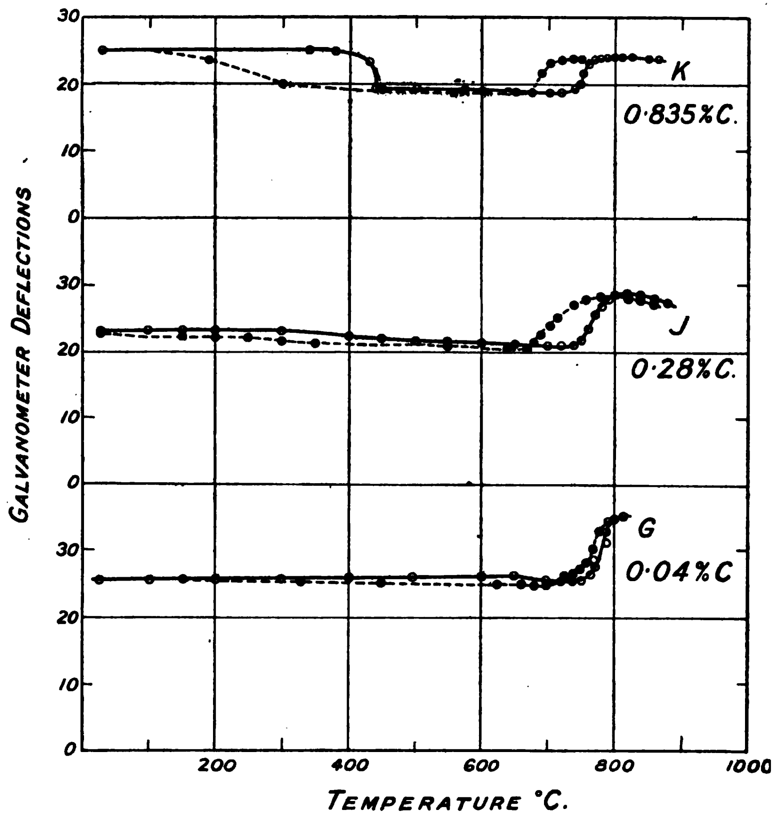


Fig. 7.—Magnetic Critical Points.

with 60 turns of nichrome ribbon. The current-carrying capacity was about 40 amperes. Because the turns of resistance wire were all wound in the same direction, there was a considerable amount of magnetic flux passing through the tube. Consequently, there was no need for an external electromagnet. The test-bar

($\frac{1}{2}$ inch diameter, 38 inches long, 0·9 per cent. carbon steel) extended through the middle of the tube. The test coil, consisting of 150 turns of insulated copper wire wound on an asbestos wood spool, was slipped over one end of the bar. The pyrometer was inserted at the opposite end from the test coil so that its iron casing would not affect the flux through this coil. The current through the furnace winding was always reduced to 20 amperes before being broken and reversed to get the deflections.

The experiment was conducted as in the previous cases with the smaller furnace. The resulting curves showed a gradual decrease in ϕ_b, ϕ_m, and $(\phi_b+\phi_m)$ at the critical temperature. A slower rate of heating failed to produce materially sharper points of inflection. It was therefore suspected that there must have been a large variation in the temperature of the furnace tube. Investigation showed that when the temperature was 800° C. in the middle of the tube, it was only 740° C. 7$\frac{1}{2}$ inches either side of the middle point. Furthermore, it was found that no attempt had been made to equalise the temperature along the middle length of tube by grouping the end windings. The electromagnetic method thus served as an indicator of the uniformity of temperature within the furnace.

It should be noted that in this experiment with the larger furnace the magnetic flux for inducing the electromotive force in the test coil was supplied by the furnace winding, while in the case of the smaller furnace an external electromagnet was employed.

Decalescent Point.

In order to determine the relation of the magnetic critical point to the decalescent point, a number of heating and cooling curves were taken of various steel samples. As no special, sensitive apparatus was immediately available, it was necessary to make use of what was at hand. After some experimenting the following mode of procedure was found to give good results in the case of the eutectoid steel:

A specimen about 1$\frac{1}{2}$ inches long was sawed off a $\frac{3}{4}$-inch bar, and then a $\frac{5}{16}$-inch hole was drilled to within $\frac{1}{2}$ inch of the end. After the bare platinum couple was inserted, the specimen

was placed in a trough of sand that could be easily pushed into the tube of the furnace, which had been previously heated to about 950° C. The heating curve was plotted from a series of temperature readings taken every 15 seconds, while the cooling curve was obtained similarly, but with the sand trough and specimen removed from the furnace.

As seen in Fig. 8, the above method gave fairly good results

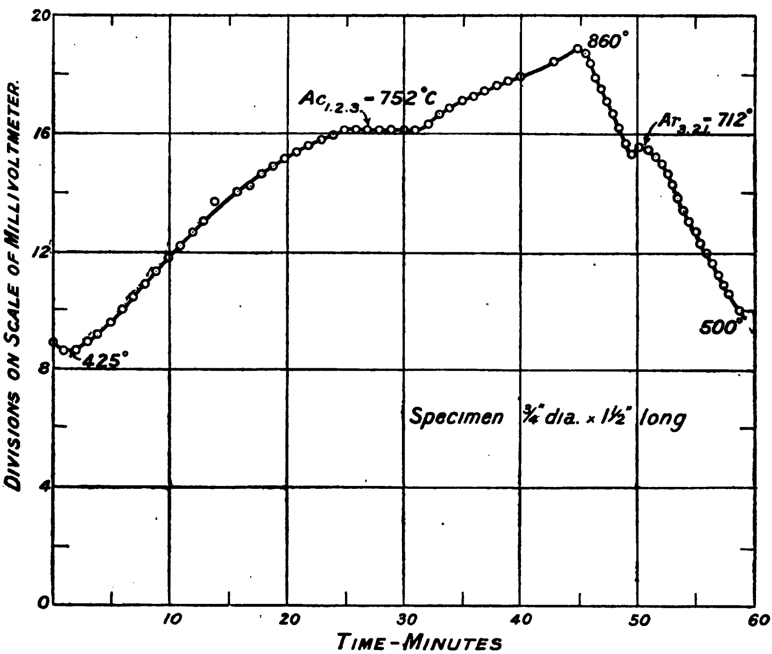


FIG. 8.—Curves for Determining Critical Points. 0·835 per cent. Carbon Steel.

in the case of the eutectoid steel sample; but no jogs whatever could be obtained for the 0·04 per cent. and 0·28 per cent. carbon samples. This was to have been expected, for low carbon steels have two and even three thermal critical points, none of which is intense enough to be detected except by very sensitive apparatus. Several tests, similar to that in Fig. 8, showed that the electromagnetic method gave practically the same results for Ac3.2.1 of eutectoid steel as the thermoelectric method, but in a direct and simple way.

Application to Annealing.

At this point it may be of interest to refer briefly to a subsequent series of tests that were made to determine the effect of various annealing temperatures and magnetic flux on the physical properties of carbon steels.[1] In these tests the critical point was determined in nearly every case by the electromagnetic method, while the temperature was observed by means ot the "Advance" thermocouple and millivoltmeter indicator as explained on p. 215.

The material tested consisted of 0·28 per cent. and 0·835 per cent. carbon steel ¾-inch round bars as furnished by a prominent steel company. The chemical analyses and physical properties of the original bars follow :

Table II.

Mark	J.	K.
Carbon	0·28 per cent.	0·835 per cent.
Manganese	0·34 ,,	0·30 ,,
Silicon	0·02 ,,	0·12 ,,
Sulphur	0·045 ,,	0·038 ,,
Phosphorus	0·015 ,,	0·012 ,,
Elastic limit	50,160	... lb. per sq. in.
Ultimate strength	75,130	142,200 ,, ,,
Elongation in 2 inches	25·8 per cent.	8·9 per cent.
Reduction of area	46·6 ,,	13·7 ,,

In order to give uniform structure and to eliminate the effects due to rolling and to the finishing temperature, all the test-bars, after being cut to lengths of 13 to 15 inches, were heated in the small electric furnace to a temperature of 1050° C., held for about twenty minutes, and allowed to cool with the furnace down to 550° C., at which point the bars were removed and buried in sand. Fig. 9 gives the average heating and cooling curve for this preliminary treatment.

The bars were annealed two at a time under conditions which, except for the variations in the maximum annealing temperature, were maintained as constant as possible in order that absolutely comparative results could be obtained.

[1] For complete details reference should be made to the article noted in the footnote on p. 210.

The following table gives some important data on the conditions of annealing :

TABLE III.

	Carbon 0·28 per Cent.	Carbon 0·835 per Cent.
Average rate of heating from 700° C. to max. temp. (Degrees C. per minute)	9·7	9·1
Average rate of cooling from max. temp. to 600° C. . .	3·6	3·2
Average time (minutes) of holding within 10° of max. temp. .	26·4	26·7

After the annealing treatment each bar was carefully machined down to the tensile test dimensions of ½-inch diameter and 3-inch length, the distance between marks being 2 inches.

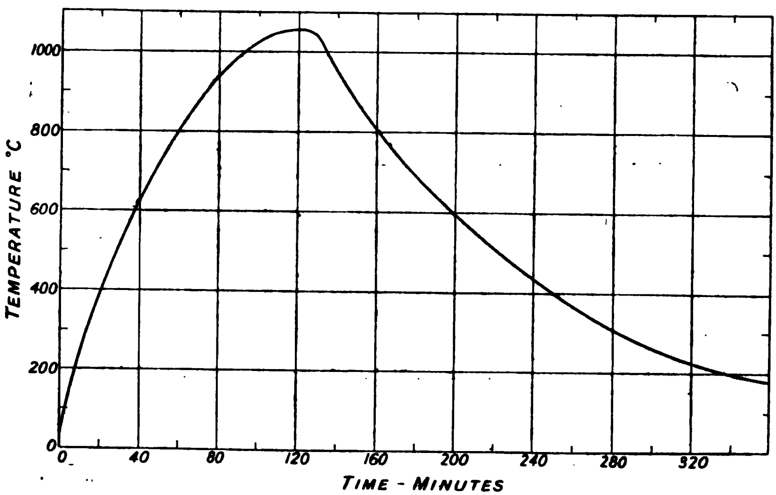


FIG. 9.—Average Heating and Cooling Curves.

RESULTS OF ANNEALING TESTS.

0·28 *per cent. Carbon Series.*—Fig. 10 shows that there were increases of 22 per cent. in the elongation, and 20 per cent. in the reduction of area when the temperature was increased from 740° C. through the critical point (about 750° C.) to 762° C., while the elastic limit, as obtained by the drop of the beam, decreased about 10 per cent. The fractures of all the test-bars were of the usual cupped and fine-grained appearance that is characteristic of this class of steels.

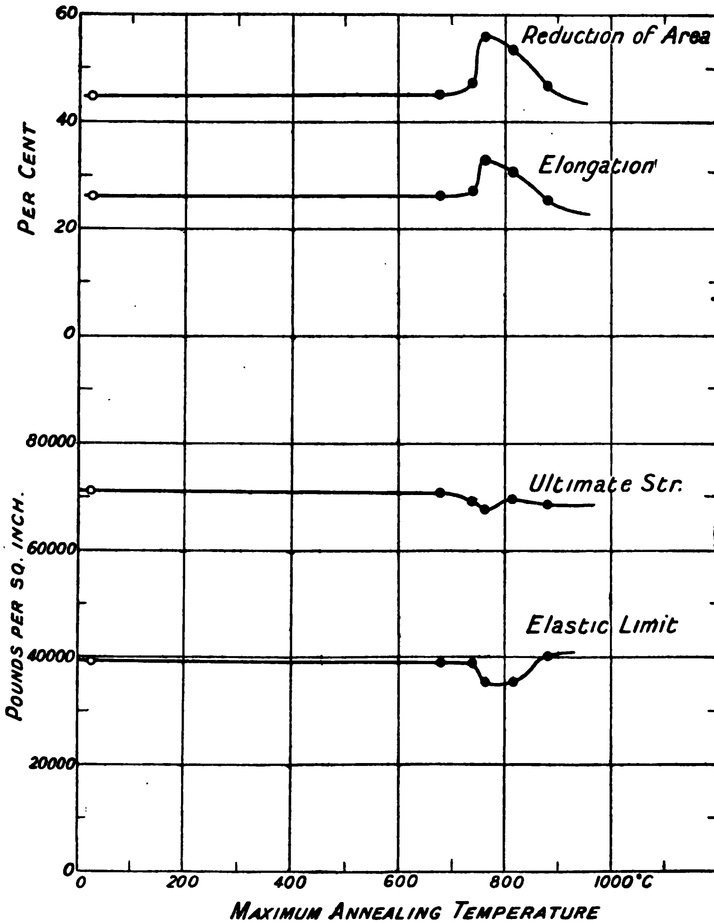


Fig. 10.—0·28 per cent. Carbon Steel.

0·835 *per cent. Carbon Series.*—In Fig. 11 can be seen the remarkable effects which small variations in the annealing temperature have upon the properties of practically a eutectoid steel. (Each plotted point represents the average of the duplicate test-bars, the open circles indicating that the electromagnetic method was *not* used.)

The ductility, or elongation, increased over 200 per cent., while the reduction of area increased over 500 per cent. when the temperature was increased above the critical point.

The ultimate strength dropped from 142,000 lb. per square

inch in the original bar as it came from the rolls, to a minimum of 94,000 when the annealing temperature was just above the

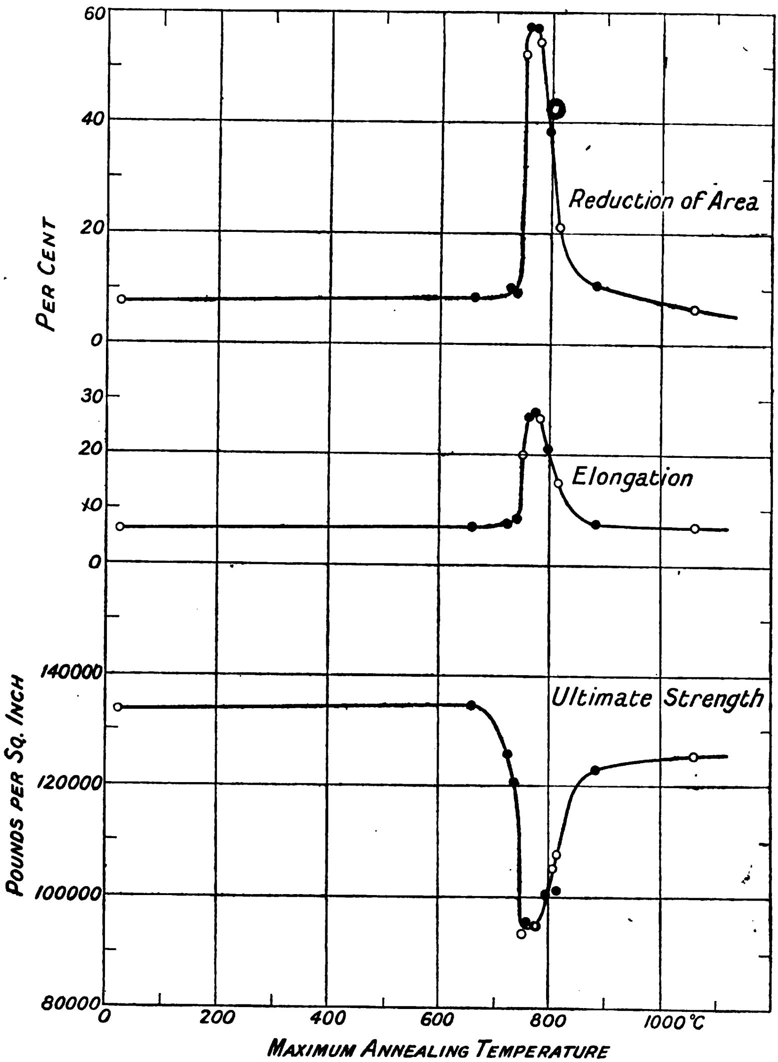


Fig. 11.—0·835 per cent. Carbon Steel.

critical point, while the yield point dropped from a probable value of 100,000 lb. per square inch in the original bar to 55,100

(as determined by a Berry strain gauge[1]) when the bar was overheated to 1050° C., and to an average value of 52,000 (as determined by the drop of the beam) when the bars were annealed in the range from 750° to 796° C.

The fractures as judged by the naked eye gave true indications of the physical properties of the test-bars. For instance, up to an annealing temperature of 740° C. the fractures were of the coarse, bright, crystalline type that is characteristic of steel previously overheated and not reheated high enough, *i.e.* to the grain-refining temperature. The original bar was so brittle that it could easily be broken into the proper lengths by making a saw-cut about ⅛ inch deep and then giving the bar a blow with the hammer. As the annealing temperature was increased above the magnetic critical point, the metal suddenly became very tough and ductile, giving the cupped, necked-down, fine-grained fracture that is characteristic of the low carbon steels. This kind of fracture occurred throughout the range, 750° to 780° C. At 796° the fracture gave evidences of approaching its former coarse condition, as it was much less necked-down and only slightly cupped.

The curves of Figs. 10 and 11 (which represent *every* test on these steels) show conclusively that under the conditions of the experiment the magnetic critical point indicated without exception the proper annealing temperature to give the finest grain and maximum ductility and reduction of area. In the case of the 0·835 per cent. carbon steel the best annealing temperature lay within the narrow range of 30° C. just above the magnetic critical point. Thus by *direct* determination of the critical point and by careful control of the temperature above that point, a steel of approximately eutectoid composition can be made to acquire the ductility of 0·30 per cent. carbon steels, and at the same time a greater elastic limit and ultimate strength than can be obtained by these lower carbon steels under similar conditions of annealing.

Discussion and Conclusion.

There are several points that might be considered briefly before concluding. First of all there will probably be some

[1] This convenient device arrived too late to be used in the other tests. Consequently the elastic limit was noted by the "drop of the beam" method, which could be applied only in the cases where the specimen was very ductile.

questions raised as to the relation of the magnetic critical point (Ac2 or Ac3.2) to the correct heat-treating temperature. This point was referred to briefly on p. 207, and the annealing tests certainly bear out the assertion made on p. 207 that the magnetic critical point was the correct heat-treating temperature (as far as annealing is concerned) in the case of 0·5 to 1·2 per cent. carbon steels, *i.e.* all those that are commonly heat-treated. Of course, the hardening of steels is another matter, and requires further research before any conclusions can be drawn. Theoretically, the correct hardening temperature is the same as that for annealing, but the rate of cooling and size of piece are important factors that must also be considered. Other things being equal, it is well known that, in order to secure equal hardness, large pieces of steel must be quenched at higher temperatures than small pieces. However, in such cases where, under given conditions, temperatures higher than the magnetic critical point are required to give certain results, it is obvious that much less error will be introduced if the critical temperature of the piece undergoing treatment is directly determined and used as a basis from which to measure, by difference, the proper heat-treating temperature (as determined by previous experiment) by means of the usual pyrometer installation. There would thus be little danger of raising the temperature so high as to coarsen the grain, and a more uniform and dependable product would naturally be obtained. The method is not intended to displace pyrometers, but rather to supplement them and to do away with their necessarily frequent calibration.

In an industrial heat-treating furnace, that has been found to heat uniformly, the electro-magnetic method could be applied to *one* of several similar pieces of steel. The electrical and mechanical details should preferably be worked out for each individual case. For instance, in small furnaces a comparatively weak solenoid would be slipped over the outside end of a small diameter steel rod that is in contact with the piece to be heat-treated. For maximum sensitivity the test coil should be slipped over the extension piece on the opposite side of the furnace. No external iron yoke would, in general, be necessary, for sharper indications can be obtained if the magnetic flux passes through the steel directly from the solenoid.

The matter of the kind of contact between the extension

pieces and steel undergoing treatment may seem to invite criticism. Many tests have shown that no special devices need be employed, the only requirement being that the contacts should be reasonably constant, such as those obtained by set-screws or sockets.

The question of simplicity suggests that some device be used that is more or less automatic; for instance, one that does not require the opening and closing of switches. If alternating current were substituted for direct current in the magnetising circuit (or solenoid), and an alternating current millivoltmeter were substituted for the direct current millivoltmeter in the test coil circuit, the deflection would be steady and continuous, until the critical point was reached, when the deflection would gradually decrease according to the amount of steel becoming non-magnetic. The sharpness of the direct current indication of the magnetic critical point might be sacrificed somewhat, because the residual magnetism would not be used, as in the case where a reversal is made from a positive residual flux to a negative total induction, as explained on p. 213.

Finally, it may be stated that the main features of this electromagnetic process, which distinguish it from all other attempts to make use of the loss of magnetism at the critical temperature, are as follows:

1. A source of magnetic flux (alternating or direct) located outside the furnace.

2. A small test coil slipped over the outside end of a small diameter steel rod which is in contact with the steel undergoing treatment.

3. A dead-beat galvanometer in the test coil circuit for indicating the change of magnetic properties.

The author desires to express his appreciation of the encouragement given and interest shown by Dr. John Price Jackson, Pennsylvania Commissioner of Labour and Industry, and formerly Dean of the School of Engineering of the Pennsylvania State College. Acknowledgment is also due to Mr. Carl L. Fehr, the writer's brother, for his valuable assistance in performing many of the experiments.

CORRESPONDENCE.

Sir ROBERT HADFIELD, Bart., wrote: We are much indebted to Professor Fehr for his interesting paper, and for the trouble he has taken in preparing the important data.

I have had a number of experiments carried out in the same direction, and find that whilst in our own case the temperature does not seem quite so restricted as that shown by Professor Fehr, on the whole the differences are not great.

The following are the particulars of my experiments, which were taken on two different types of steel—one containing 0·30 per cent. manganese and the other 0·80 per cent. manganese. The former

TABLE I.—*Mechanical Tests on Carbon Steel Annealed at Various Temperatures.*

	C.	Si.	Mn.
a. Low Manganese . .	0·85	0·17	0·32
b. Higher „ . .	0·79	0·06	0·84

Steel No.	Treatment.	Shock Test.				Ball Test.
		"C" Nick.		"No" Nick.		
	Degrees F.	Kgm.	Angle. Degrees.	Kgm.	Angle. Degrees.	
2150	700	0·2	1	17	28	277
„	725	1	1½	18	26	283
1392A	750	1·2	1	14	26	{ 238 228
2150	„	1·0	3	21	49	221
1392A	775	1·3	1½	22	58	{ 212 217
„	800	1·9	3½	23	63	{ 207 217
2150	„	2·2	4	22	53	230
1392A	850	0·7	½	13	21	{ 228 238
2150	„	1·2	2½	16	34	252
1392A	900	0·2	1	9	11	{ 258 262
2150	„	1·1	2	16	28	268
1392A	950	0·7	½	12	5	{ 262 265
2150	„	0·7	1	15	52	264
1392A	1000	0·6	1	8	24	{ 269 274
2150	„	0·5	1	14	19	271
1392A	1050	0·1	½	9	7	{ 269 277
2150	„	0·5	1	15	23	271

was selected as being practically the same analysis as Professor Fehr's specimen. The analysis of each was as follows:

		C.	Si.	S.	P.	Mn.
No. 1392A.	Rolled bar, ⅞ inch octagon . .	0·85	0·17	0·04	0·03	0·32
No. 2150C.	Hammered bar, 1 inch diameter .	0·79	0·06	0·04	0·03	0·84

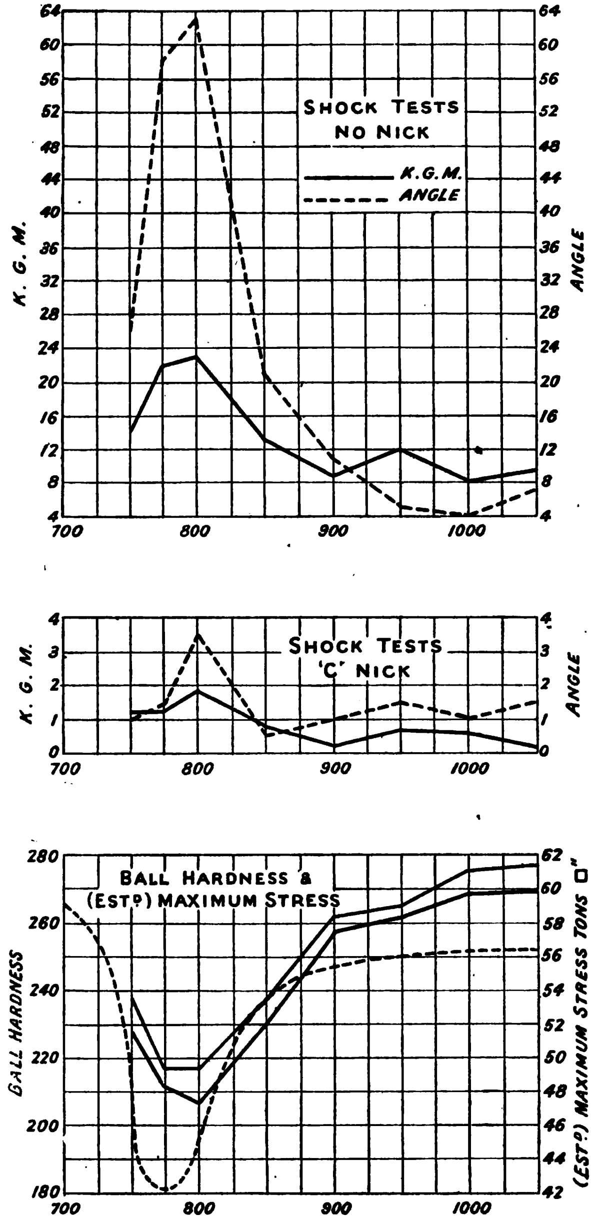


FIG. A.—Effect of Annealing at Various Temperatures on Carbon Steel (Low Manganese). Carbon, 0·85; Silicon, 0·17; Manganese, 0·32. Cooled in furnace. Annealing Temperature — °C. (Compare Fig. B—Higher Manganese.) The dotted curve shows the results obtained by R. B. Fehr. The two solid lines are duplicate tests on the same specimens.

The bars were cut into 1½-inch lengths, and heated to successively increasing temperatures, as shown in Table I. (p. 229), cooling in furnace in each case.

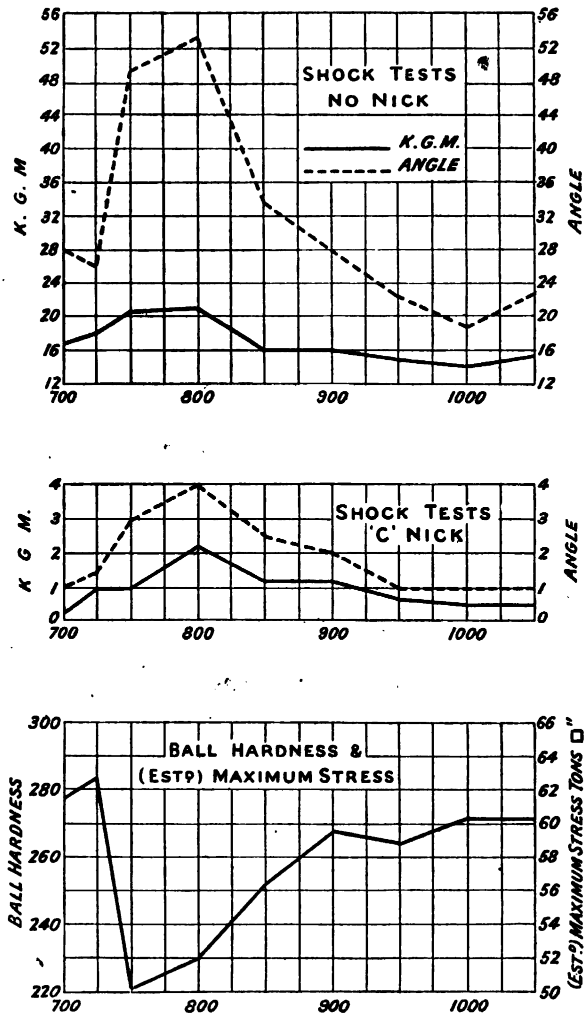


FIG. B.—Effect of Annealing at Various Temperatures on Carbon Steel (Higher Manganese). Carbon, 0·79; Silicon, 0·06; Manganese, 0·84. Cooled in furnace. Annealing Temperature — °C. (Compare Fig. A—Low Manganese.)

Shock tests, "C" and "No nick," were cut from the specimens and ball tests taken on the shock pieces.

The results obtained are shown in Table I., and diagrams Fig. A

and Fig. B. The former diagram, Fig. A, shows Professor Fehr's results for comparison.

The conclusions arrived at are that the results of my experiments generally bear out Professor Fehr's results on the steel containing 0·3 per cent. manganese, that is, rather narrow limits of temperature round about 800° C. for producing the maximum softness of this steel.

The corresponding steel with 0·8 per cent. manganese shows a very much more gradual effect of temperature annealing, indicating that steel with higher manganese does not require such precise annealing as regards temperature as compared with material containing lower manganese.

ORIGIN AND DEVELOPMENT OF THE RAILWAY RAIL IN ENGLAND AND AMERICA.[1]

BY G. P. RAIDABAUGH (SPARROW'S POINT, U.S.A.).

THIS paper is condensed from a much larger work which was begun a number of years ago for the purpose of finding the cause for the then large numbers of different rail sections in use, and with the intention of learning something of the rail and its service that would be of advantage in the designing of rolls for rolling the rail.

Railways first came into use about two hundred years before the introduction of the locomotive steam-engine. About the year 1630 the collieries of the North of England made use of wooden tram or waggon ways for the purpose of reducing the labour of hauling coals to the place of shipment.

They consisted at first simply of rough pieces of timber

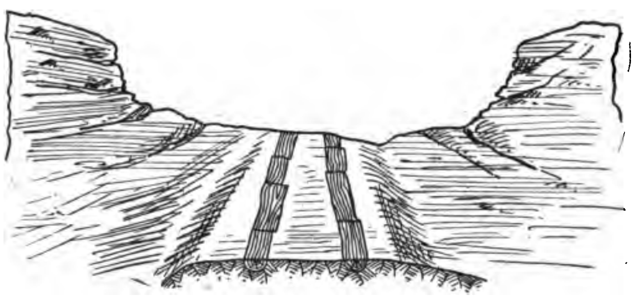


FIG. 1.

imbedded in the roadway (Fig. 1) in such a way as to make a tolerably smooth track for the wheels of the carts or waggons.

Later, sleepers with wood rails were used (Fig. 2, R1).

With this arrangement the removal of a broken or worn out

[1] This paper was completed in January 1914, and is printed from a "blue-print" manuscript copy presented by the author to Mr. E. S. Maslin of Ebbw Vale, who brought it to the notice of Mr. F. Mills, the managing director of the Ebbw Vale Company, and by the courtesy of Mr. Mills the paper has been presented to the Institute for publication. It is to be recorded with great regret that the author, Mr. G. P. Raidabaugh, died early in 1916. His son, Mr. J. A. Raidabaugh of Harrisburg, Pa., U.S.A., has kindly sanctioned the publication of the paper.

rail injured the sleeper in consequence of the peg holes becoming too large.

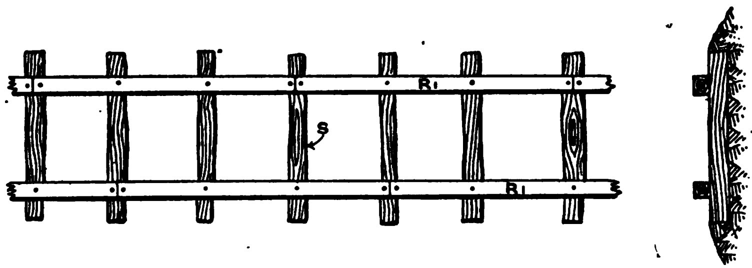


FIG. 2.

This condition was improved by nailing an upper rail (Fig. 3, R2) on to the lower rail (R1), when the upper rail could be frequently renewed without injury to the sleepers (S).

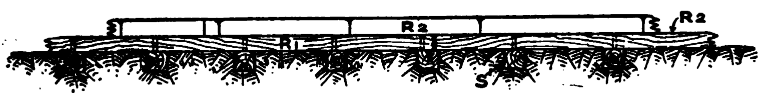


FIG. 3.

From descriptions that have come down to us of these old tramways, we learn that the benefit to be derived from the use of iron was known at an early date, as the following abstract from one of them proves. "When the draft was harder than usual, in consequence of a steep ascent or a sharp curve in the line, friction was diminished by nailing to the wooden rails thin strips or plates of malleable iron" (see Fig. 4). But we should

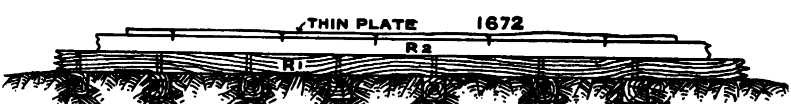


FIG. 4.

remember that at that time these strips could not have been other than roughly forged, and such as we nowadays would consign to the scrap pile.

Another writer, in the year 1672, describes a wooden railway which he had seen at Newcastle in England, an abstract from

which says: "The manner of the carriage is by laying down rails of timber from the collieries to the river exactly straight and parallel, and bulky casts are made with rowlets fitting these rails, whereby the carriage is so easy that one horse will draw 4 or 5 chaldrons of coal" (8 or 9 tons).

These old wooden tramways continued in use for nearly 150 years without any further improvements, but several attempts were made during this period to use stone rails instead of the wooden rails, although it was soon found that what the stoneways gained in durability they lost in smoothness.

The first great advance towards our present system of railways was by the introduction of cast iron plates upon the wooden ways. This advance, one of the early writers tells us, was the result of accident rather than of design, in the following words: "About the year 1767, when the price of pig iron was very low, it occurred to one of the proprietors of the Coalbrookdale ironworks, as a means of keeping their furnaces at work, to cast bars in such a form as to admit of them being laid down on a wooden railway in use at the works. This, it was thought, would save the expense of repair to the railway; but if a sudden rise should take place in the price of iron the rails (see Fig. 5) could be taken up and sold as

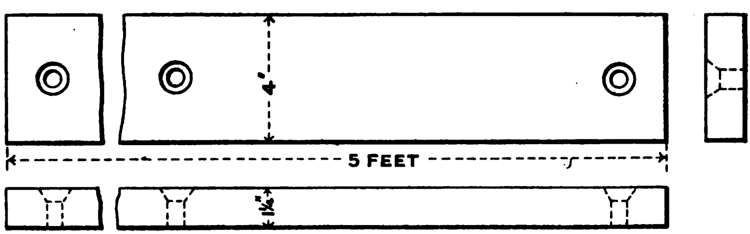


Fig. 5.

pigs. These plate rails were 5 feet long, 4 inches wide, and ½ inch thick. They were cast with three countersunk holes in them for convenience of nailing them on to the wooden rails." The road was said to be successful, and it was pointed out as an advantage (which we would now consider to be a great misfortune) that vehicles could be turned off the track with great ease in consequence of the absence of a guiding flange.

Plate rails later, when wrought iron came into use, were

called strap rails, and continued in use, to some extent at least, for about 100 years.

About the year 1776 the iron rail was improved by the addition of an upright flange A (Fig. 6), rising 3 inches above the path of the waggon wheels. These rails were at first laid down upon cross sleepers with the flanges turned inward.

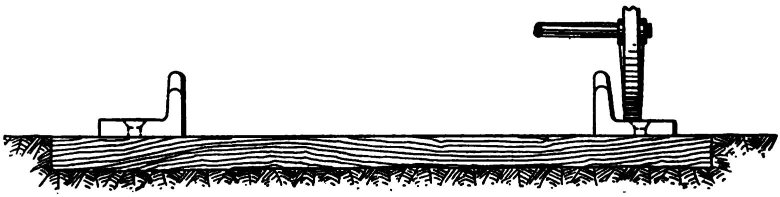


Fig. 6.

They were still further improved in the year 1793 by the addition of brackets to support the flange, and ribs or beads cast upon the under side of the rail to strengthen it between the stone supports (see Fig. 7), which by this time had become the custom. These stone blocks were 18 inches to 20 inches square and 8 inches to 10 inches deep, Fig. 7, showing end view of the rail as improved,

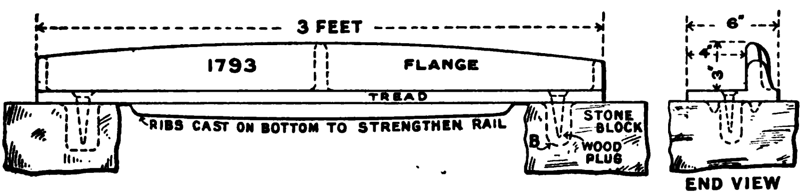


Fig. 7.

also showing the manner of securing them on to the stone blocks. The rails were secured to the stone blocks with spikes driven into hard wood plugs which were inserted in the holes B in the stone blocks. However, rails of this construction did not prove to be satisfactory, as stones and dirt would accumulate upon the tread of the rail which caused much friction, and when higher speeds were required tended to throw the carriage off the line.

A number of these old rails are in the Baltimore and Ohio Railroad collection of old railway appliances.

The defects of the Coalbrookdale rails were remedied by the

introduction of edge rails, Fig. 8 showing one of the earliest, patented in England by William Jessop in the year 1789. This rail is a fish-bellied rail and was supported upon stone or wooden

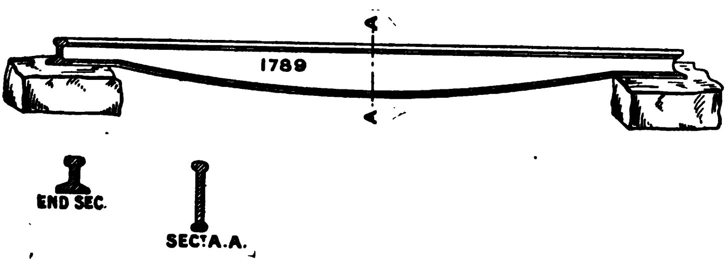


FIG. 8.

blocks, the rails having a flat base for a short distance at each end where they rested upon the blocks, to which they were secured in the same way as the plate rails.

Fig. 9. *Cast Iron Edge Rail of* 1797.—This rail was supported by a cast iron chair. These are said to have been the first chairs

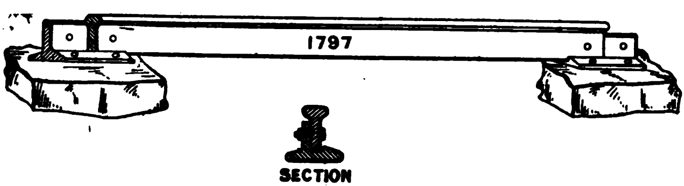


FIG. 9.

adopted. The rails were secured to the chairs by bolts through the stem of rail and the chair. The chairs were spiked to the stone blocks or sleepers.

Fig. 10. *Cast Iron Rail of* 1802.—Rails cast 4 feet 6 inches long. They were of oval section, the large diameter being vertical (see No. 1), and beneath each end of the rail a dovetailed block A was cast which fitted into a cast iron chair or sill B. This sill was imbedded in the roadway. The wheel had a grooved tire fitting loosely on the rail; but it was soon found that the groove became so deepened by wear as to fit the rail tightly, so that it caused much friction. An attempt was made to remedy this

fault by making the bearing surface of the rail flat and the wheel was made to correspond to it (see No. 2).

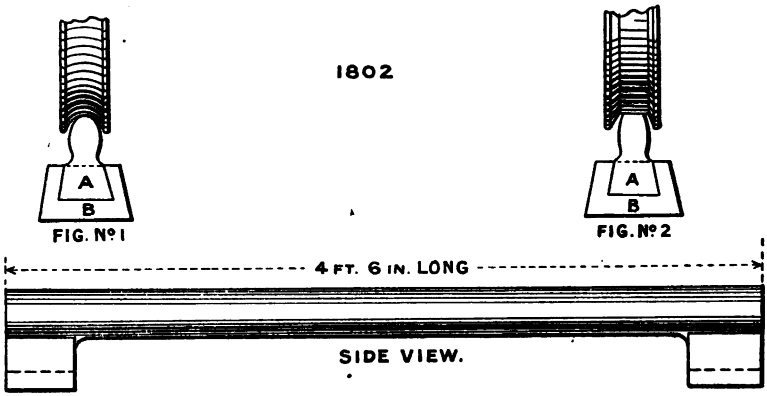


FIG. 10.

Fig. 11. *Cast Iron Rail of* 1808.—Designed to be laid without the use of bolts or spikes. Pins (A) were cast on the under side of the rail, at the ends, where they rested upon the stone blocks. C,

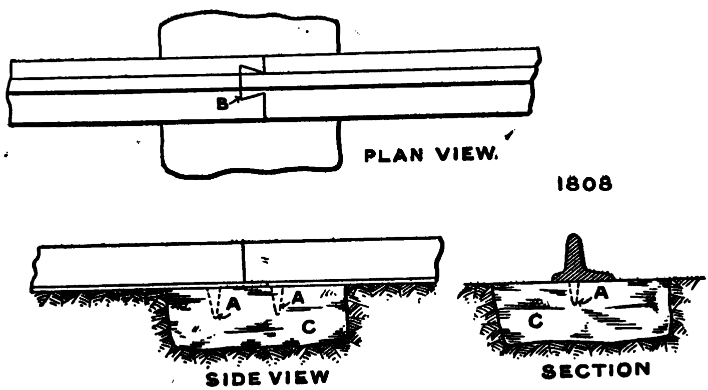


FIG. 11.

the stone blocks, have holes drilled in them to fit the pins on rail. The joints between the ends of rails were made in a dovetailed form, as shown at B, thus doing away with the necessity of bolts and spikes.

Fig. 12. *Cast Iron Plate Rail of* 1813.—This rail has a curved

flange and a bead cast on the under side of rail, and is secured to the stone blocks in the same way as shown in Fig. 7.

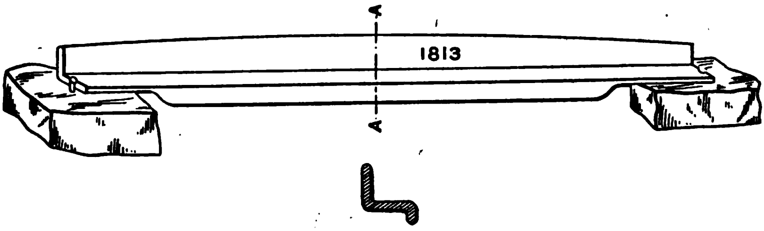


Fig. 12.

Fig. 13. *Cast Iron Edge Rail patented by Stephenson and Losh in* 1816.—Mr. Wm. Strickland, a prominent engineer of his day, describes this rail in the year 1826, after his return from a visit to England, as a "cast iron rail 4 foot long, a fish-bellied rail 5 inches deep at the centre A and 2 inches deep

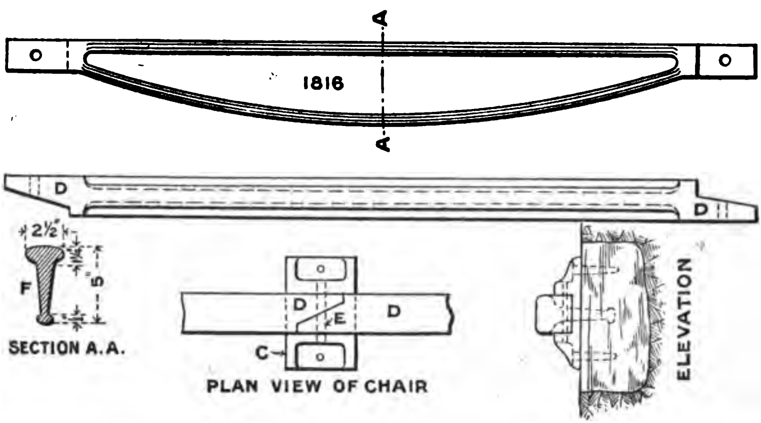


Fig. 13.

at the ends DD, where they rest in the chair C, with the ends of rails cast solid, formed to make a half lap joint D, and secured in the chairs by pin E. Some of the old prints of this rail and chair show this pin to be a wooden one. F. Cross section of rail at A."

Cast iron rails were used for many years after this time. A patent was granted to John W. Bay, of Harrisburg, Penn., in 1844 for a cast iron rail to be cast with a bar of wrought iron in the head for strength.

About the year 1846 the three cast iron rails shown by Fig. 14 were proposed for use upon American railroads. These rails

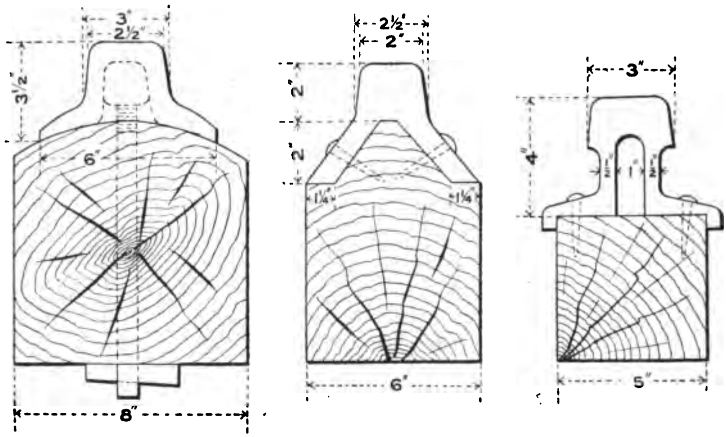


Fig. 14.—Proposed Cast Iron Rails, 1846-1848.

were to be cast 10 feet long. The manner of securing them in the track upon longitudinal sills is clearly shown by the drawing.

We have not found that there were a great many of those cast iron rails used upon our early American railroads. But we do know that a part of what is now a branch of the Northern Central Railroad, running from Sunbury to Shamokin, Penn., was first laid with the cast iron rail.

But the cast iron rails were not without strong advocates, for as late as some time between the years 1846 and 1850, Mr. I. C. Trantwine, a very prominent railway engineer of that time, recommended the use of cast iron rails upon a hundred miles of railway he was then constructing.

Rails of malleable iron of the square or flat form were first

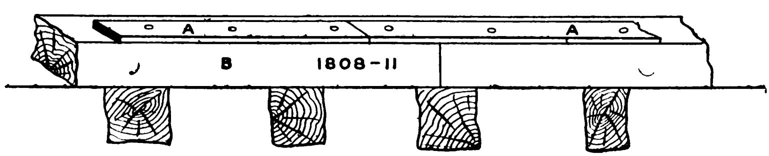


Fig. 15.

made and used in the years 1808 to 1811, this being the only form the rolling machinery of that time could produce (see Fig. 15).

These rails were flat or square bars of iron, A. The flat bars

were 2 inches to 3 inches wide, ½ inch to ¾ inch thick, with holes drilled and countersunk for nailing them on to the wooden rails, B. Rails of this form continued in use in this country for many years, and are known in history as the strap rail.

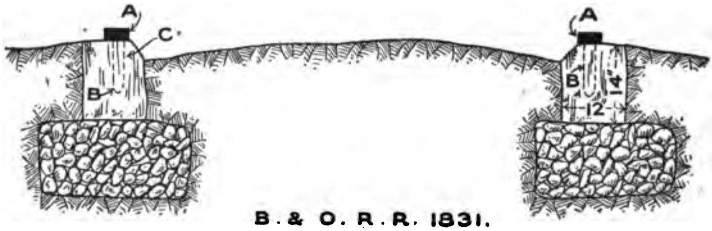


Fig. 16.

The above, Fig. 16, is a section of the Baltimore and Ohio Railroad in 1831. "Long granite slabs were substituted for the wooden rails. These slabs were dressed to shape, and holes B drilled for securing the strap rails A to the slabs. These rails were 2½ to 4½ inches wide and ½ inch to ⅝ inch thick. The granite stringers were laid in trenches partially filled with broken stone."

Several of these old stone stringers, with the strap rails spiked to them, may be seen at the National Museum, Washington, D.C. Fig. 17 shows sections of some of the strap rail used on the Amboy

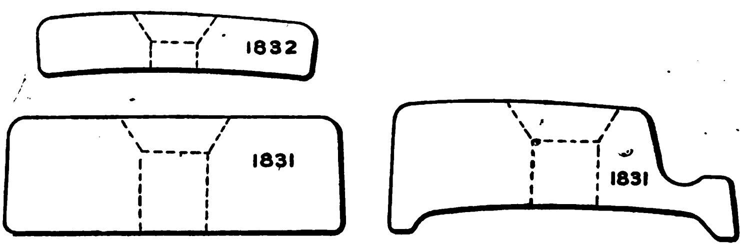


Fig. 17.—Strap Rails used on Amboy Division, 1831-1832. Full size.

Division of the P.R.R. in the year 1831, previous to the introduction of the Stevens rail (or as we now know it, the tee rail). These drawings were made from sections of the rails preserved by the P.R.R. Company at their station, Broad Street, Philadelphia, Penn.

The flat or strap rail was the only form of rail that could be rolled upon American mills up to the year 1844, at which time there

were probably more miles of track laid with these rails than with all other types of rails.

These rails were very imperfect and difficult to keep in the track, as the following abstract from a New York paper of May 30, 1844[1]: "*Railroad Casualty.*—The cars on the railroad a short distance east of Rome, New York, came in contact with a 'snake-head,' when the strap rails, owing to the constant wheel pressure, would tear loose from the wooden sills to which they were nailed (see Fig. 15), and followed the wheels frequently with force sufficient to penetrate the car floor to the injury of the passengers [they were called snake-heads]. The crash was tremendous and the cars were torn to splinters."

As late as the year 1868 there were four miles of these rails laid upon wood stringers. This was a branch of the Marietta and Cincinnati Railroad between Westborough and Hillsborough, Ohio, and we believe is now a part of the B. and O. South-West system.

Many attempts were made to form a cheap and durable rail by the combination of wrought and cast iron, but no plan was successful until the method was introduced about 1820 of rolling iron into any required shape. With the improvements in the method of rolling began the development of the wrought iron edge rail, the Birkenshaw being the first one rolled, a patent for which was granted to John Birkenshaw, of the Bedlington Ironworks, in October 20, 1820 (Patent No. 4503).

The drawings here shown on Figs. 18 to 20 are copies from the plates accompanying the patent specifications.

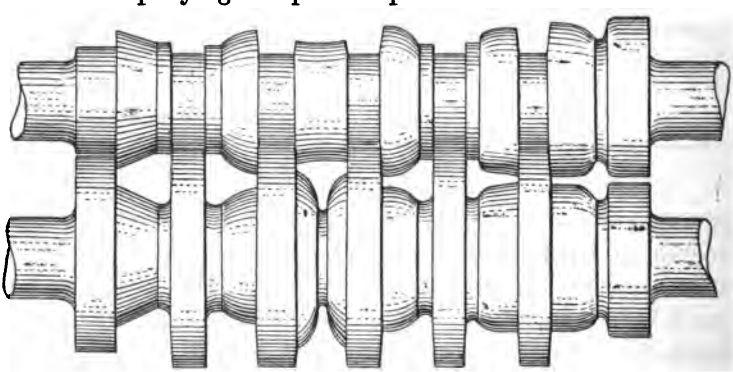


FIG. 18.—Birkenshaw's Rail Mill, 1820.

[1] See Swank's "Iron in all Ages."

The set of rolls, Fig. 18, are no doubt the first ever made and used in the manufacture of shaped wrought or malleable iron rails.

Mr. Birkenshaw desired to roll the rails 18 feet long, to obviate the evils of the great number of joints in the line, and further proposed to weld the ends of the bars together as they were laid down; however, I do not think this was done, as I have found no mention of it in any of the old descriptions of this rail.

Mr. Birkenshaw showed considerable ingenuity in the designing of this the first set of rail rolls, as they could not be improved much, if at all, to-day for rolling bars of that shape on a two-high mill. The upper surface of the rail was to be made slightly convex to reduce friction, and they were to be supported upon blocks and chairs, the points to be secured with a pin. See Fig. 19, rail and chair, No. 1.

Figs. 19 and 20 show the four different sections of shaped rails as covered by Birkenshaw's patent. He says the wedge-

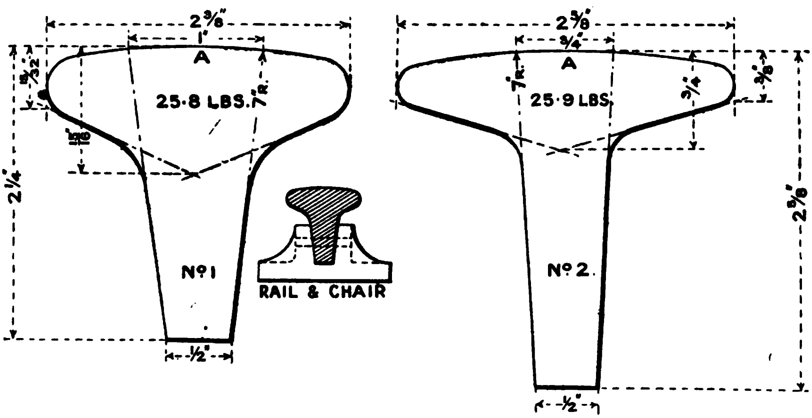


Fig. 19.—Birkenshaw Rails. Patented 1820.

shaped rails, as shown by Nos. 3 and 4, are made in that shape because the strength of a rail is always proportioned to the square of its breadth and depth. Hence the wedge form of rail possesses all the strength of a cube equal to its square, but that the weight of metal used may be reduced still further and sufficient strength retained by forming the bars or rails as shown by Nos. 1 and 2. He further states in his specifications that he prefers

the form as shown by No. 1. This rail No. 1 is the first rail ever rolled with a head for the wheel to run upon, and was rolled at

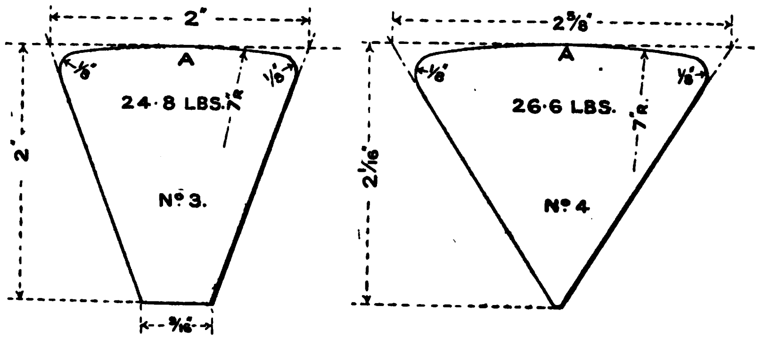


FIG. 20.—Birkenshaw Rails. Patented 1820.

some time between 1820 and 1825. It was first used on the Stockton and Darlington railroad.

By the year 1830 the Birkenshaw rail had become changed to the fish-bellied rail, as shown by Fig. 21. These rails were

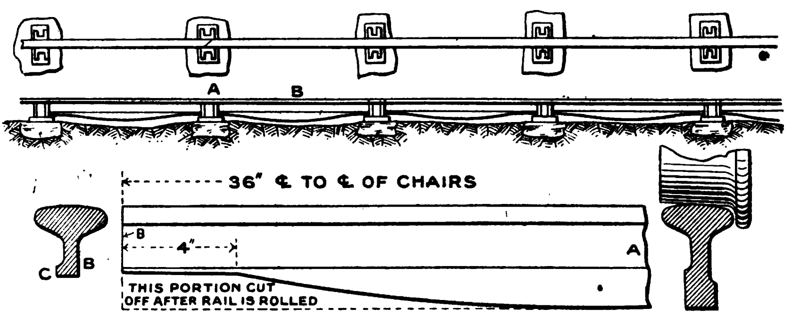


FIG. 21.—Birkenshaw Fish-Bellied Rail.

15 to 18 feet long, divided into 3-foot fish-bellied spaces as shown in figure. They were rolled parallel and the metal sheared out to form the fish-bellied spaces, the lower drawing showing one half of one of the spaces and section of rail at A and B.

When looking up the history of this rail the thought uppermost in my mind was, why did they make the rail in this form, as it is a very difficult one to make. From what we have learned about them there is no doubt but that the fish-bellied rail came into use through the views held by some of the railway engineers

of that day, that a railway should be of equal solidity at all points on the line, and as they believed the rail would be stiffer and more unyielding at the points where they rested in the chair and were supported upon the stone blocks, for that reason it would be necessary, in order to equalise the stiffness of the line, to take some of the metal from the rail at that point.

Wm. B. Adams, in a book published in 1862, states that the fish-bellied rail was a "mechanical error," and that there was a false datum in assuming the sleepers or stone supports to be an unyielding fulcrum, instead of a yielding point. This was soon discovered and the rail made parallel again.

In the year 1830 the Boston and Lowell railroad was laid with this rail. One of the original rails laid upon that road, with the cast iron chair and wrought iron wedges for securing the rail in the chair, is in the possession of the late Mr. R. K. Wood's estate at Sparrow's Point, Md.

The next rail to come out was known as the Clarence rail, Fig. 22; this is also an edge rail and was rolled as early as 1830. A number of the early American railroads were laid with this

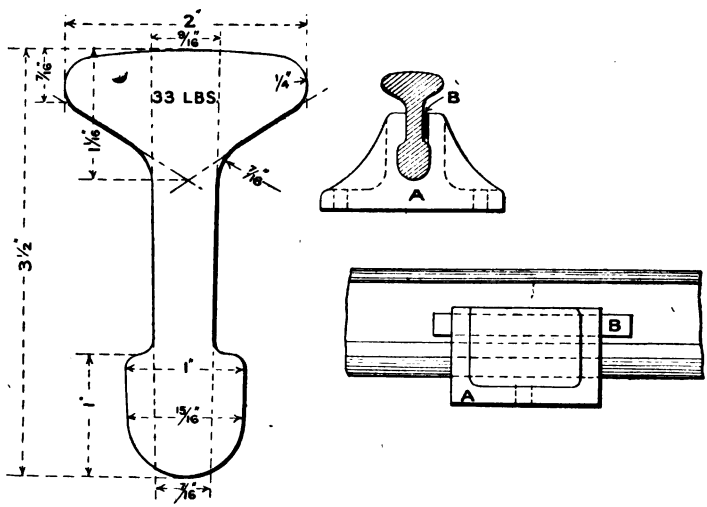


Fig. 22.

rail: the Boston and Lowell single track, the Germantown and Noristown, and the Alleghany Portage were some of the roads using this rail. The rail, here shown about three-quarter size, is taken

from a piece of one of the rails laid upon the latter road. A short section of this rail has been preserved by the P.R.R. Co., at their Broad St. Station, Philadelphia, Penn. I also have a short piece of this rail, laid on the Germantown and Noristown road in the year 1831.

This rail was said to be an improvement on the first Birkenshaw rail, as it could be secured in the shoes or chairs without the use of pins at the points. The small drawing to the right shows the rail and chair, the rail held in a vertical position by the thin iron wedge B, the lower projections on the rail preventing it from lifting.

It was later found that the driving of the iron wedge broke a great many of the chairs. This was remedied by changing the wedge side of the chair to take a wooden wedge about 1¼ inch thick, which soon became the permanent practice.

Between the time this rail came out and the year 1840 there were quite a number of designs and modifications of this rail made and used (see p. 252).

The tee rail now in general use is an American invention. In September 1830 the "Directors of the Camden and Amboy Railroad instructed Robert L. Stevens, President and Chief Engineer of the road, to visit England and report on railroad matters there, and directed him to purchase all iron rails, which they preferred to the wooden rail plated with strap iron" (see pp. 235, 236). A short time after Mr. Stevens sailed, and during the voyage he designed the first tee rail (see Fig. 23) with a base. It is said Mr. Stevens designed this rail by whittling it out of wood, until he got one to suit him.

"Mr. Stevens was familiar with the English rails, and saw that they required expensive chairs to hold them in the track, and knew that they were not adapted for use in this country, where iron was scarce and dear."

Mr. Stevens added the base to the English tee rail (see Birkenshaw and Clarence rails), which dispensed with the expensive chairs. He also designed the hook-headed spike and the tongue B, which have since developed into the railroad spike and splice bar of to-day.

Fig. 23, showing his proposed rail, which was to be rolled with the projections A on the base of the rail at every 2 feet where it rested on the supports and the tongue B on the end of

the rail, to join the rails together. He did not find it practical to have the rails rolled as originally designed, with the projections and tongue as shown, so they were omitted and the section was changed. It has been somewhat of a task to deter-

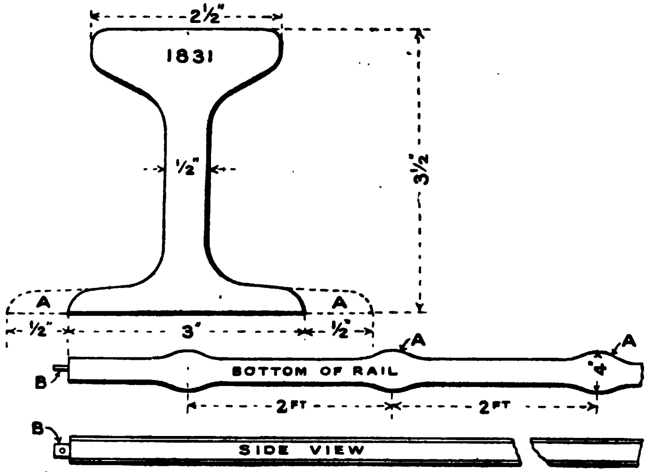


FIG. 23.—Robert L. Stevens' Design of first "T" Rail.

mine what the cross section of the first tee rail was, but after a careful study of all the evidence found at this late day we know that one of the two sections on Fig. 24 was the first tee rail, with the preference largely in favour of section B, as this one corresponds more fully to the descriptions of the rail laid on the Camden and Amboy road, as given by the historians of that time, than any other rail we have found.

The section B conforms very closely to a description of the tee rail laid on that road in 1831, in Wood's "Treatise on Railroads," published in 1832, which says the rails were of rolled iron 16 feet long, 2⅛ inches wide on top, 3¼ inches at the bottom, 3½ inches deep, the neck ½ inch thick, the weight 209 lb., 89·18 lb. per yard. The slight difference in weight could easily come through the reproduction of the rail from the badly worn and rusted section, B1 on Fig. 25, which was the only piece of the rail we could find and is in the possession of the P.R.R. Co.

Tanner, in a book called "Canals and Railroads of the United States," published in the year 1841, in describing the Camden and Amboy Railroad, says of the rail used upon it: "The rail

was of the H pattern and weighed 41 lb. per yard, and gives the height at 3½ inches."

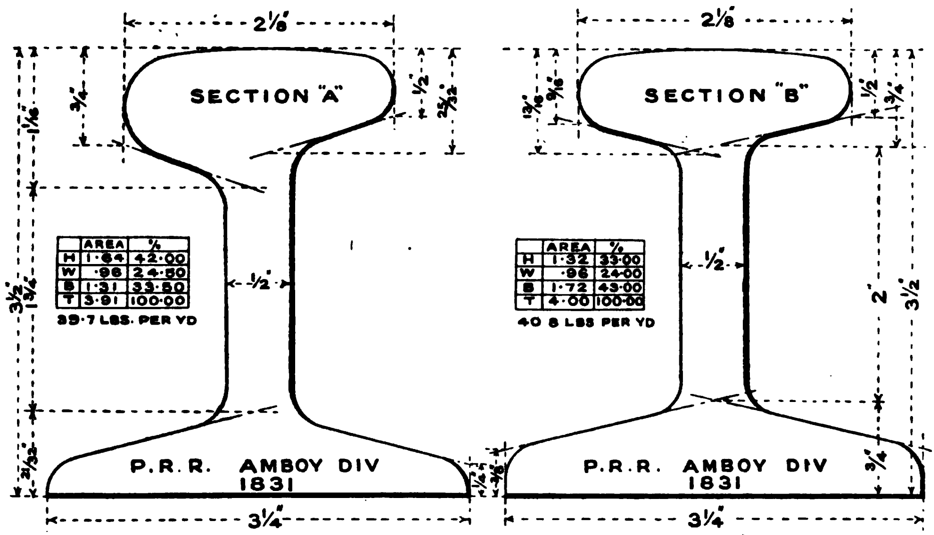


FIG. 24.

The sections A1 and B1 on Fig. 25, badly worn and rusted as they are, were used to reconstruct sections A and B in Fig. 24, and by their aid and through the descriptions we find of them, some of which we have given, I believe that the sections A and B in Fig. 24 are as nearly accurate as can be made at this late day of the first tee rails made and used. The tracings of the two rails here shown were kindly sent to me by Mr. C. W. Whitemen of the P.R.R. Co. These two, and several others preserved by the P.R.R. and one or two sections at the National Museum, are all that we were able to find of the first tee rails, and they were all badly worn and rusted.

The first shipment arrived at Philadelphia on the ship *Charlemagne*, May 16, 1831.

The following is an abstract from Mr. Stevens' letter to the English ironmasters: "Gentlemen, at what rate will you contract to deliver at Liverpool, say from 500 to 600 tons of railway of the best quality iron rolled to the above [see Fig. 23] pattern in 12 to 16 foot lengths, to lap as shown in the drawing with one hole

at each end, and the projections on the lower flange [base] at every 2 feet; cash on delivery." Mr. Stevens met with much trouble in finding anyone who would undertake to roll the rails,

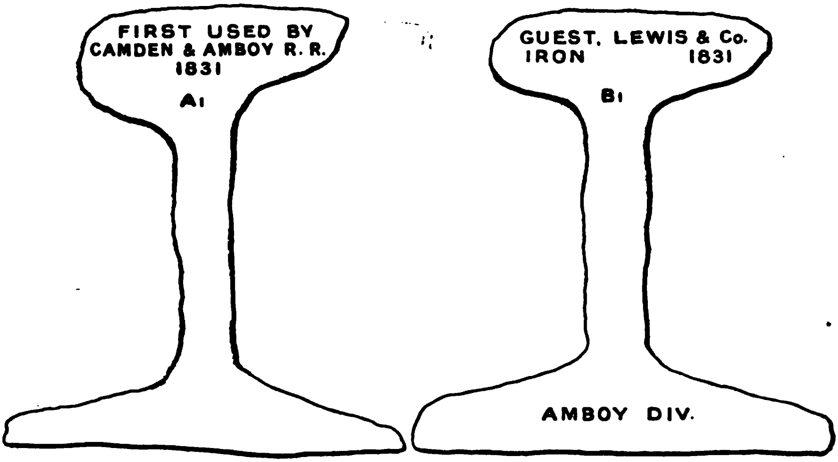


Fig. 25.

and did not succeed in finding one until he put up a money forfeit which should cover any damage to the mill while rolling them. The limits of this brief sketch will not permit of taking up that side of the subject.

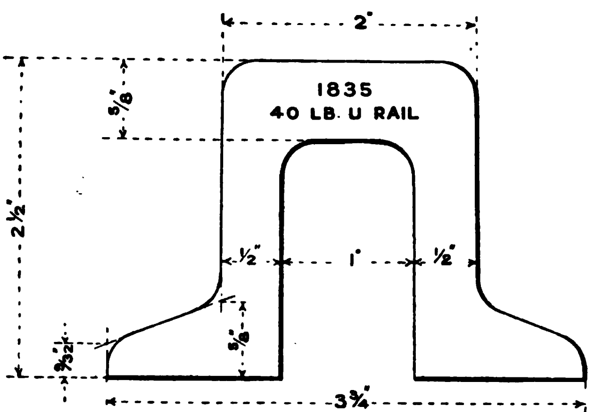


Fig. 26.

Some time between the years 1831 and 1835 the U rail, now known as the bridge rail, came out, the name "bridge rail" coming

from the custom of generally laying this rail on longitudinal sills, the sills resting upon sleepers, which gave to the track somewhat the appearance of an extended bridge.

This section (p. 249) is a copy of drawing sent to the Franklin Institute by Mr. I. C. Trantwine in the year 1835 and marked "in use on the Wilmington and Susquehanna Railroad." This section is of interest, as it fixes the date at which it came out.

I have not been able to find out positively where this rail first originated. But from what I have learned of it I think it was at the Dowlais Ironworks in Wales.

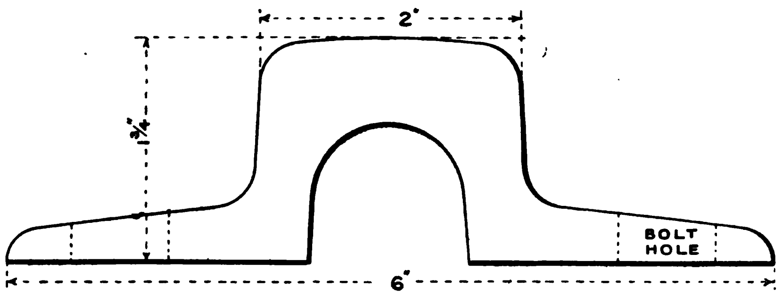


FIG. 27.

The bridge rail shown on Fig. 27 was in use on the Great Western Railroad, Mass., in the year 1835. There were a great many patterns of this rail in use during the early years of American railroads, as a considerable mileage was laid with them.

In the year 1837 the Lock rail came out (Fig. 28). At first it was known as the double tee rail, but now known as the double head rail. This rail, unlike the Stevens rail, did not come into existence at the first attempt, but is a development of the Birkenshaw rail, as it was found that the Birkenshaw rail with the narrow base where they rested in the chairs, quickly destroyed both the rail and chair at these points. The Lock rail was devised to overcome this fault by increasing the width of the lower head.

It was thought at first that the increased width of the lower head would not only remedy the fault but would permit of reversing the rail, when the top or working head became worn out. It was soon found this could not be done successfully, as the rail still wore badly at the points where they rested upon the cast iron chair.

This resulted in the adoption of a rail similar to No. 2, known

as the bullhead rail, with the lower head the smallest, which permitted of using more metal in the top head for traffic wear.

These two types of rails are still very popular with English railroad men, and are largely used at this time.

We have now shown all of the different types of rails that were

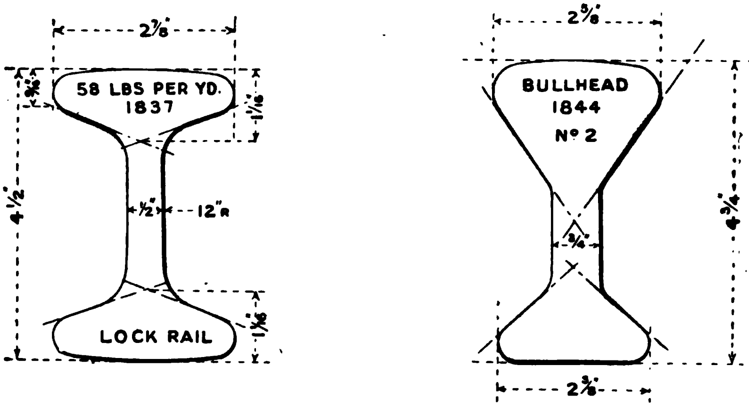


FIG. 28.

used upon steam railroads, all of which were in use prior to the year 1844, when heavy shaped rails were first rolled in America. All of them except the Stevens double-head and bullhead rails have since gone out of use.

Fig. 29 (p. 252) shows a few of the many changes through which the original Birkenshaw rail went while developing into the British standard bullhead rail of 1905.

At the beginning of the year 1844 there were 4185 miles of railroads in America. All the rails used upon them except strap rails, and a few cast iron rails, were imported from England. The manufacture of heavy wrought iron rails in this country was commenced in that year, at the Mount Savage Rolling-Mill, Alleghany Co., Maryland. There, at some time between April and November, was rolled the first edge rails ever made in America.

The rail was of the U or bridge pattern known as the Evans pattern of the Dowlais Ironworks and weighed 40 lb. per yard.

This rail (Fig. 30) was awarded a silver medal by the Franklin Institute at St. Louis in November 1844.

The following is a copy of the proceedings of the Institute, exhibit No. 2705:

" A bar of railroad iron of the U form rolled by the Mount

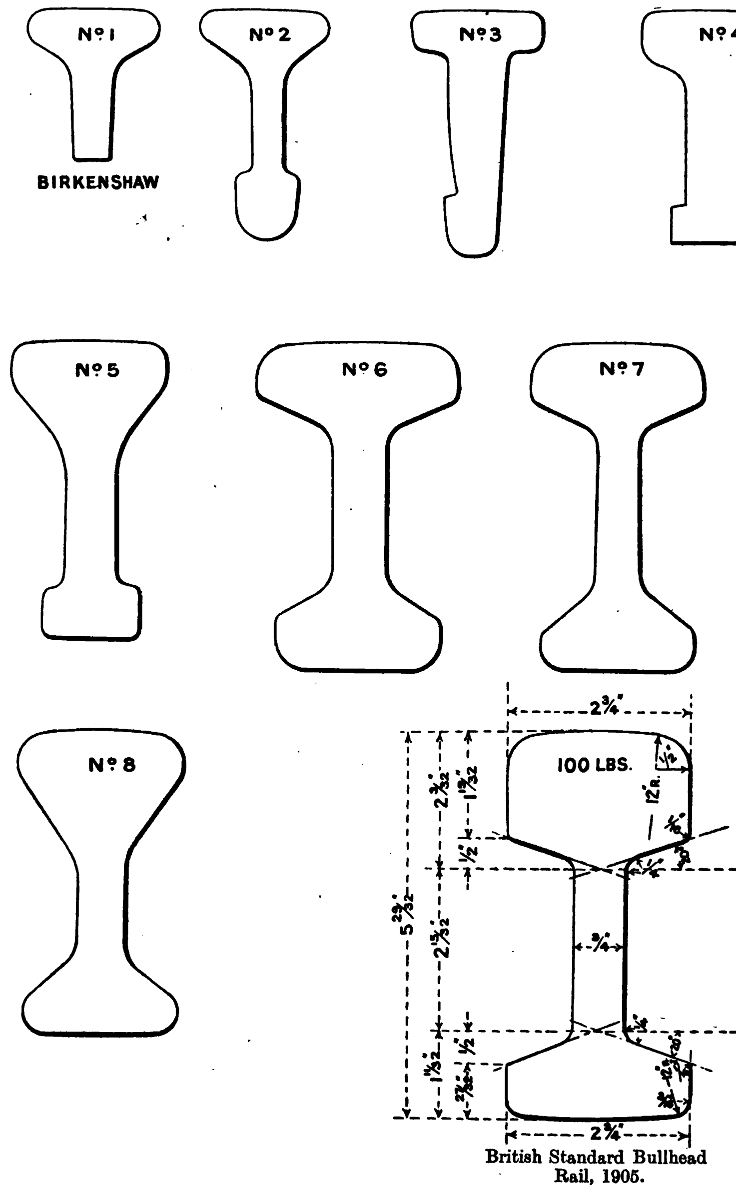


FIG. 29.—Development of the Birkenshaw Rail.

Savage Ironworks, near Fronburg, Md., and forwarded by Colonel Young, manager. This bar is 18½ feet long and weighs 40 lb. per lineal yard. It is part of a lot of several hundred recently rolled there for a branch of the Baltimore and Ohio Railroad leading to the works. This bar is amongst the first early rails yet rolled in the United States, and it demonstrates beyond the reach of cavil that edge rails can be well manufactured in America.

"This bar is well proportioned, sound, and well finished. It is the first ever exhibited here of American make, and we hail it with pleasure as the beginning of a new manufacture and award it a silver medal."—JOHN WEIGAND, Chairman of Committee.

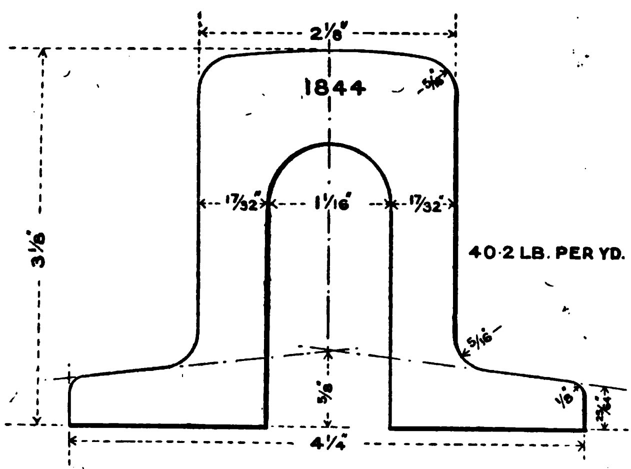


FIG. 30.—Cross Section of the First Rail Rolled in America.

Fig. 30, showing the rail as reconstructed from descriptions found of it, and the tracing below, Fig. 31, and one other piece of the rail equally badly worn and rusted, are all we could find of the first edge rail rolled in America, as we know the section shown on Fig. 30 to be.

Swank states "that about 500 tons of this pattern, weighing 42 lb. per yard, was laid in 1744 on a part of the road then being built between Mount Savage and Cumberland" (B. & O. R.R.). Soon afterwards rails weighing 52 lb. per yard were rolled at Mount Savage Rolling-Mill for the road leading from Fall River to Boston.

This 52-lb. rail has been given the credit by some writers as being the first rail rolled in this country, but that is evidently a mistake, as all the evidence points clearly to the rail shown by Fig. 30 having been the first heavy shaped rail rolled in America.

The first tee rails made in America were rolled at the Mentone Rolling-Mill, Danville, Penn., in the month of October 1845.

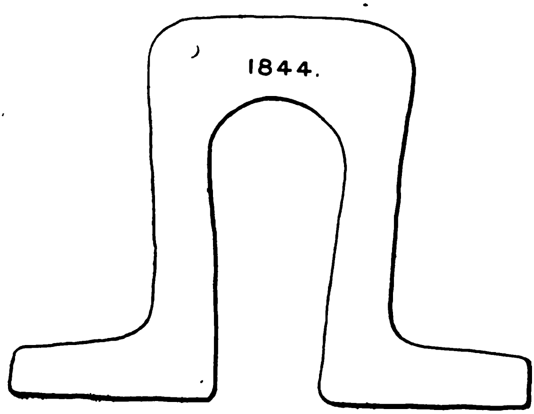


Fig. 31.

This mill was built especially for rolling rails. The first rail rolled was a section of the tee rail known as the pear-head type.

We know that the rail shown on Fig. 32 is not a correct section of the first tee rail rolled at that mill, as all records of it have been lost or forgotten. But I learned from some of the men who worked in the mill when it first started, that it was a pear-head rail with the ends of the flanges ½ inch to ⅝ inch thick, and a very heavy web. The rail shown opposite corresponds more closely to their description of the rail than any other of the old pear-head rails I have found. For that reason I have shown it as a type of the first tee rail rolled in America. Rails of this pattern were very popular during the first twenty years of American rail making. The principal cause for this was that the designing of the rail sections was left largely to the mill men, who would naturally only design such sections as were easy to roll.

We have not found that American railway engineers took any great interest in the improvement of the rail section previous

to the year 1865, about twenty years after America had begun to roll rails.

The sections shown on p. 256 are several of the various shapes the tee rail took on in the twenty years following the beginning of their manufacturing in this country.

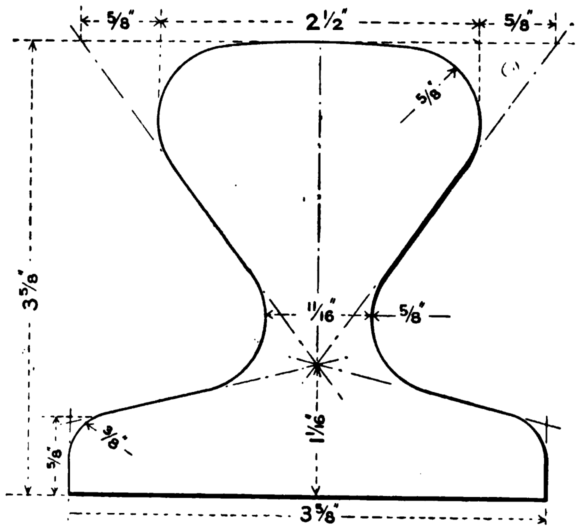


FIG. 32.

The years between 1844 and 1865 were very prolific in the production of compound rails (Fig. 34, p. 25). These rails were laid in the track with the several parts so as to break joints, when new; they made a splendid track, but it was soon found that the several parts of the rail could not be kept together, the bolts and rivets which held them together wearing out very rapidly and permitting the rails to become loose in the track. A considerable mileage of them was laid, but as they could not be made to stand the test of work, they have long since gone out of use.

The period of the greatest importance in the history of the rail was between the years 1847 and 1857, as during that time the Bessemer process of making steel was perfected. It is a remarkable fact that this, the second great epoch in the history of the railway rail, like the first, should be largely the result of accident rather than of design (see Fig. 5), as neither of the two

men who were most prominent in the development of that process began to experiment with the thought or expectation of making steel.

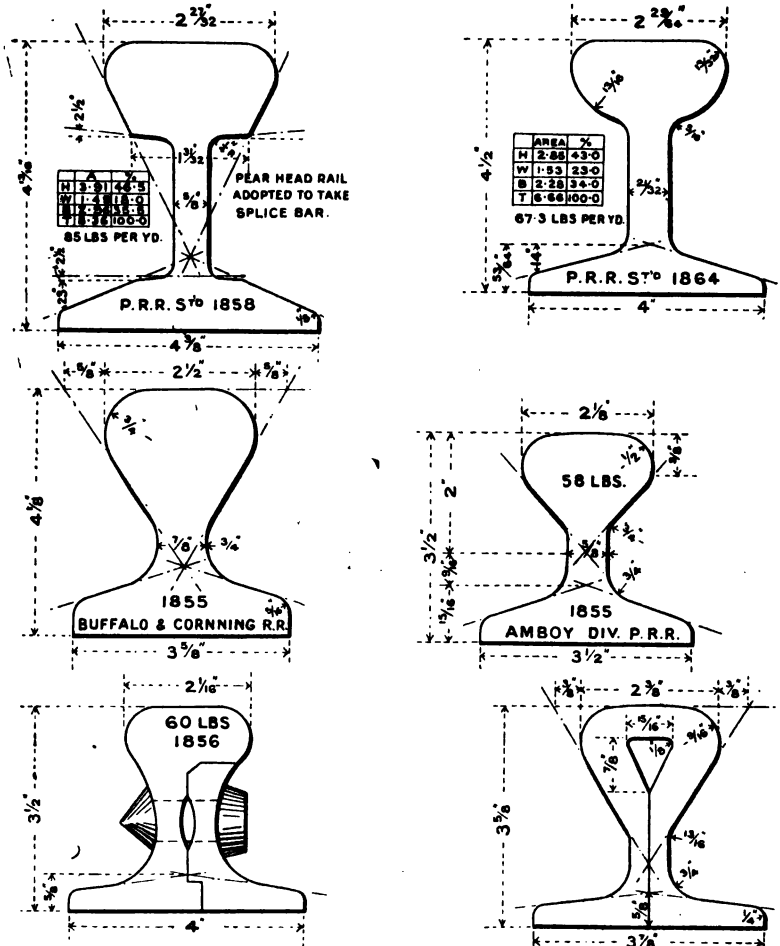


FIG. 33.

Mr. William Kelby, a resident of Pittsburg, Pennsylvania, began his experiments at Eddyvill, Kentucky, in the year 1847, with the idea in view of refining and decarbonising melted cast iron with the use of an air-blast, and by that means saving the

fuel required in the refining fires in refining the iron for his forge fires.

Sir Henry Bessemer conceived the idea of making malleable iron by introducing air into the fluid metal in 1855.

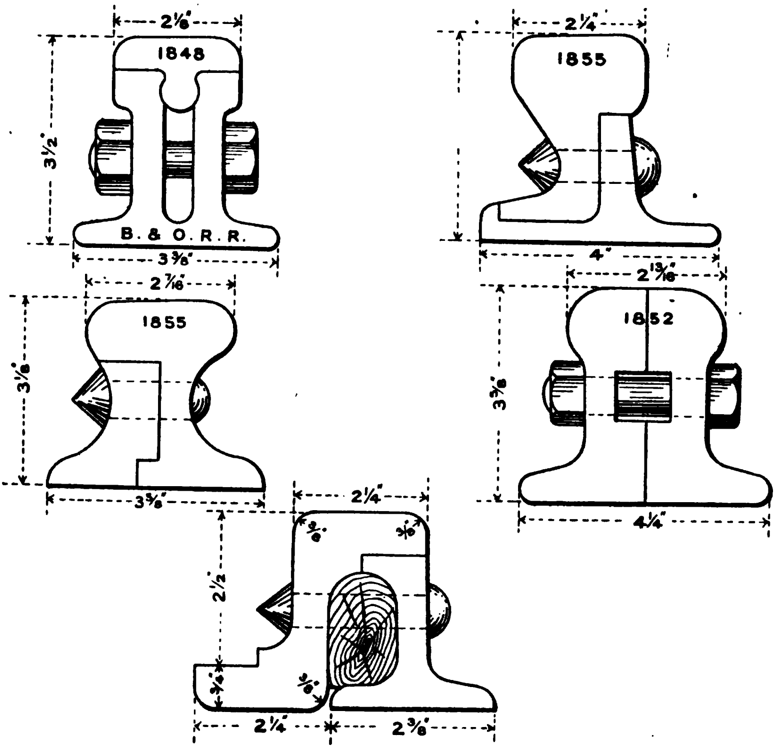


FIG. 34.

Kelby and Bessemer both failed to obtain any successful results in making steel up to the beginning of the year 1857, when the third man, Mr. Robert F. Mushet of England, supplied the missing link in the chain, by the invention of a process for recarburising the melted, decarburised, and desiliconised iron as produced by the Bessemer process at that time. This perfected the Bessemer and Kelby process, and we can say that the production of cheap steel dates from that time.

Pending the publication of Mushet's patent early in 1857

and during the erection for him of a blowing apparatus and small converter, Mushet obtained from the Ebbw Vale Company a small supply of Bessemerised hæmatite cast iron. This he melted in ordinary steel melting pots, adding to the 44 lb. charge of each pot, when melted, 2 lb. of melted spiegeleisen. From this mixture ingots of 6 to 700 lb. were cast. One of the ingots was sent to the Ebbw Vale Ironworks and rolled into a double-headed rail, which was sent to the Derby railway station on the

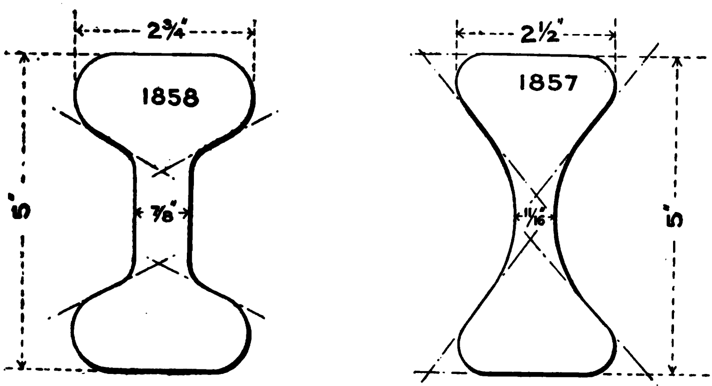


FIG. 35.

Midland Railroad. This rail was laid down there, early in 1857, and was in use for sixteen years; and history tells us that in that time more than 1,250,000 trains and a like number of detached engines and tenders passed over it.

The two rails on Fig. 35 are sections that were being rolled in England at that time, and it is quite probable that the first Bessemer steel rail was like one of them or nearly so.

It was not until seven years later that there was any Bessemer steel made in America. The first Bessemer steel in that country was produced at a small experimental plant established at Wyandotte, Michigan, in the year 1864.

The first Bessemer steel rail rolled in America was rolled at the North Chicago Rolling-Mill on May 24, 1865, from ingots cast at the experimental works at Wyandotte—Mr. William Durfee, superintendent.

I met with considerable trouble in my efforts to obtain a cross-

section view of this the first Bessemer steel rail rolled in America (see Fig. 36). Finally Mr. D. S. Mattias, of the Illinois Steel Co., kindly supplied the drawings.

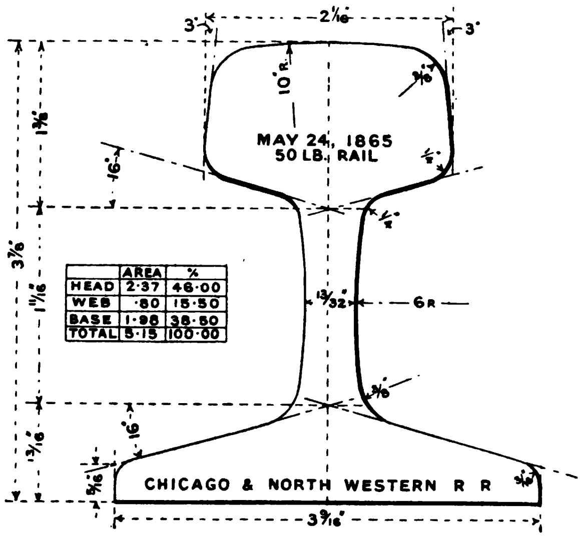


FIG. 36.—First Bessemer Steel Rail rolled in America.

In the year 1867 the first Bessemer steel rails upon order in the way of regular business in the United States were rolled at the Cambria Iron Co. Works, Johnstown, Penn.

Mr. James M. Swank, in his history of "Iron in all Ages," says, "The first Bessemer steel rails rolled upon order in the United States were rolled at the Cambria Works in August 1867."

Mr. R. W. Hunt, in an address delivered before the A.S.M.E., said: "I have already placed upon record in a lecture before the Franklin Institute, Philadelphia, January 21, 1889, that the first commercial rolling of steel rails was at the Cambria Works in August 1867, on an order for the P.R.R. Co., from steel made by the Pennsylvania Steel Co., at their Steelton plant. These rails were rolled on a three-high 21-inch train. At first the steel ingots were drawn into blooms under steam-hammers.

"Mr. George Fritz, superintendent of the Cambria Works, concluded that this was not the proper manner of treating the material, and Mr. A. L. Holley, then in charge of the Pennsylvania Steelworks, sustaining Mr. Fritz in his experiments, had ingots

cast 8½ inches square. These ingots were bloomed in a set of blooming-rolls prepared by Mr. Fritz and placed in one set of the 21-inch rail train housings. The ingots were rolled to 6½ inches

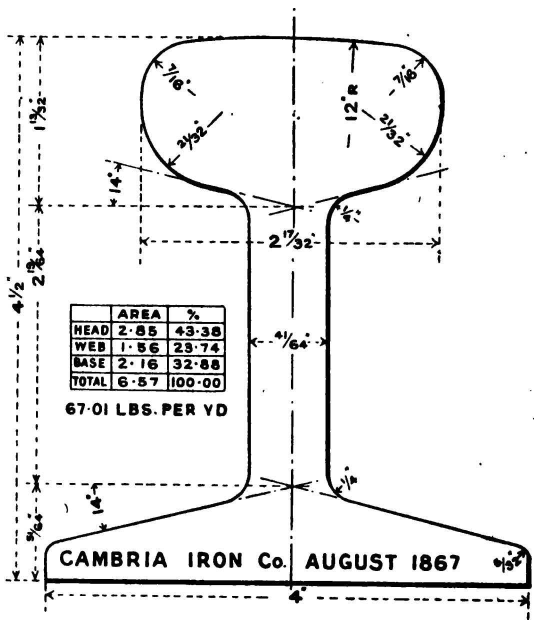


FIG. 37.—First Bessemer Steel Rail rolled on Order in America.

square, recharged in the heating furnaces, wash-heated, and then rolled into rails. This practice was successful; and I believe this was the first cogging or blooming mill."

The section shown on Fig. 37 is a cross section of the first Bessemer steel rail rolled on order. I received this through the courtesy of Mr. H. H. Weaver, Assistant to the General Manager of the Cambria Steel Co., and it is their old section No. 29.

In this short sketch of the steel rail industry we have not space to speak of the many heart-breaking experiences and failures met with by the men who were prominent in the work of developing the Bessemer process in this country.

Mr. R. W. Hunt, in his "History of the Bessemer Manufacture," sums them all up in one sentence: "But I do know from the Wyandotte, to say nothing of later experiences, that it required

faith made perfect, to carry one through the sea which seemed to be bounded by no shore."

On the preceding pages we have endeavoured to show the gradual development of the rail from the beginning to the advent of the Bessemer steel rail, 1867. We now take up the American development of the rail. Up to this time I do not find that there had been any decided steps taken by our American railroad men and engineers towards improving the form of the rail, except by Mr. A. L. Holley.

In the year 1865 Mr. Ashbel Welch designed a rail very much like Fig. 37, and a few years later he designed the rail shown below, Fig. 38, the first of the thin flanged rails.

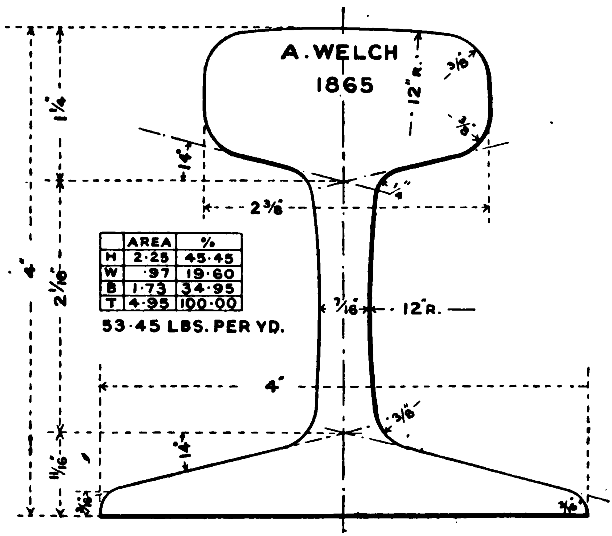


Fig. 38.

Mr. Welch says of this rail "that previous to 1867 the steel rail laid down in this country, made from the iron ráil sections then in use, were unnecessarily heavy; and so proportioned, that much of the metal did no good, and I determined to try a section in which all the metal possible should be in the head."

He further says in his Memoir attached to the report that he met with considerable trouble to place a contract for these rails, as the railmakers were not inclined to risk the rolling of

them on account of the extremely thin flanges, and that after five or six years of use none of them have failed in the web.

He also stated at this time that he would be in favour of placing 50 per cent. of the total metal of the rail in the head.

By the year 1874 the idea advanced by Mr. Welch a few years previous to that time, that all the metal possible should be placed in the head of the rail, began to take hold of our railroad engineers, and in that year Mr. Octave Chanute published the rail shown as No. 1 on Fig. 39. This type of rail soon became very popular, and I find that there were many different patterns of this rail rolled and used in the next twenty years. No. 2 on this figure is

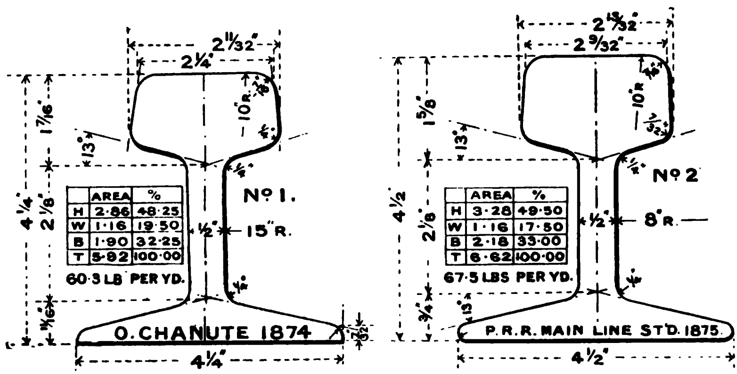


Fig. 39.

a later development, and we have found some of the Chanute rails with as much as 53 per cent. of the total metal in the head.

In a short time rails of this type entered largely into use and became known as the Chanute rail. But they were not without opposition, as it was not a great while until these large-headed and thin-flanged rails started a controversy between the railroad engineers and the railmakers as to their merits and demerits which continued for many years, in fact at this time, 1907, has not been finally settled. Notwithstanding the opposition they met with many thousands of tons of them have been made and put in the tracks since 1874, as there are many of them in use at this time.

The No. 1 rail shown is undoubtedly a descendant of the rail shown on Fig. 36, as the first Bessemer steel rail rolled in the United States, with the flange somewhat thinner.

When once the railroad men began to improve the rail, they went at it, "with hammer and tongs," as I find amongst the old templates and section books in my possession over sixty different sections of the Chanute rail alone, to say nothing of the many other types.

At the same time Mr. Chanute brought out his rail, Mr. R. H. Sayer designed the rail shown at No. 1, Fig. 40. The Chanute and Sayer rails were among the very few rails made at this time with a bevel to the sides of head.

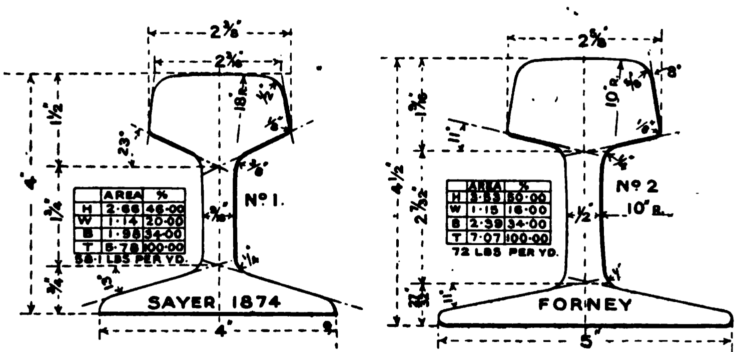


FIG. 40.

Some years later Mr. Forney designed the rail shown at No. 2. This rail has more bevel to the side of the head than either the Chanute or Sayer rails.

The Sayer and Forney rail never became as popular as the Chanute rail, although there were some ten or twelve different sections of them made and used, and at the present time they are not in use to any great extent.

At the time Mr. Chanute designed the 60-lb. rail (Fig. 40) in 1874, for the Erie Railroad, there were in use on that road twelve patterns of steel rail, twenty-nine patterns of iron rail, and ninety-six different styles of joint fixtures and rail fastening devices.

In 1888, Mr. Robert W. Hunt, one of the most prominent pioneers in the Bessemer steel rail trade, brought out a set of rail sections as standard, consisting of 60, 65, 70, 75, 80, 85, and 90 lb. rails, Fig. 41 showing the 60 and 90 lb. sections.

The sections were all of the same design and with nearly the same proportion of metal in the several parts as head, web, and base for all of the sections.

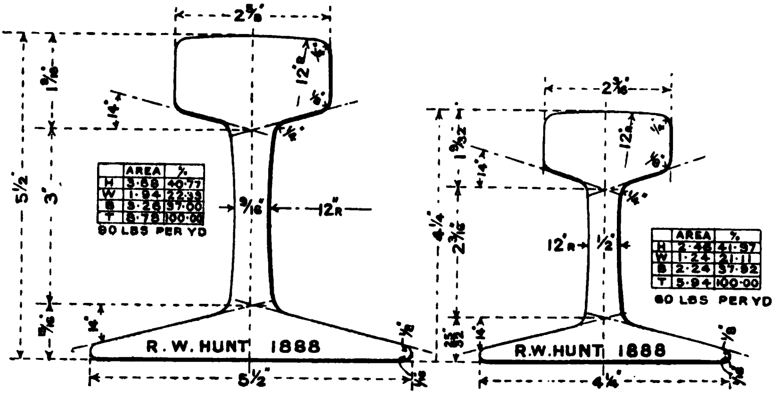


FIG. 41.

As this was the first time in the history of American rail designing that a series of sections had been presented in a practical manner, and was a decided advance over anything

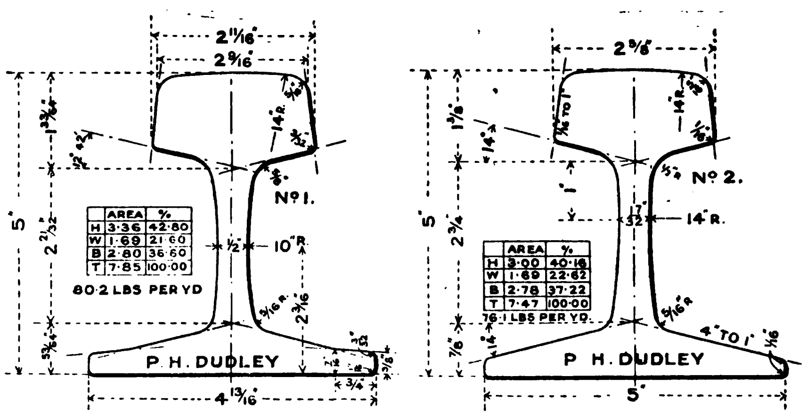


FIG. 42.

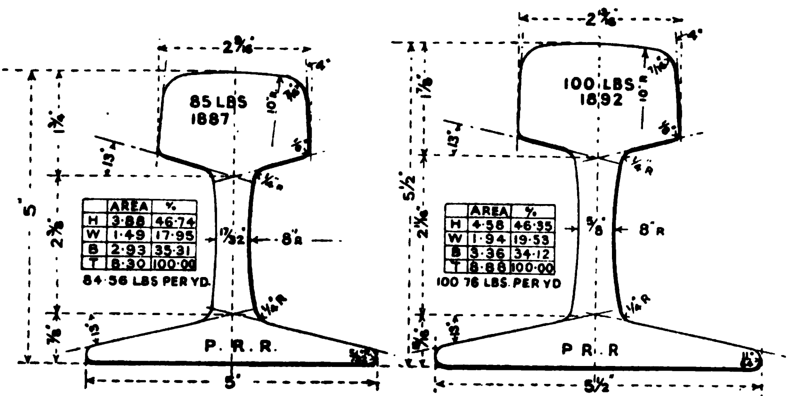
that had yet been done towards the end in view—that of originating a series of rail sections that could or would be accepted as standard rails by the railroad companies and the railmakers.

Notice the close resemblance of these rails to the A.S.C.E. rails which finally became the standard sections in 1893.

Mr. P. H. Dudley, a prominent railroad engineer, in the year 1883 designed the 80-lb. rail shown as No. 1, Fig. 42, for the New York Central and Hudson River Railroad. Mr. Dudley said of this rail: "It was the pioneer of the broad shallow head and thick base for heavy rails."

The Dudley rail soon became quite popular and many of them are being made to the present time.

In the year 1887 the Pennsylvania Railroad Co. adopted the 85-lb. rail shown in Fig. 43 as their standard rail, and in 1892 the 100-lb. rail was made their standard.



	AREA	%
H	3·88	46·74
W	1·49	17·95
B	2·93	35·31
T	8·30	100·00

	AREA	%
H	4·58	46·35
W	1·94	19·53
B	3·36	34·12
T	8·88	100·00

FIG. 43.

In the contention between the railroad engineer, the engineering societies, and rail manufacturers as to the relative merits of the large-headed and of the small-headed rails, these rails are usually classed with the large-headed rails.

But when they are compared with the average rail designed and rolled in America since the year 1866, we find them to be about the average, so far as the percentage of metal used in the several parts of the rail as head, web, and base are concerned. For the purpose of comparison we took forty-five different sections that have been made since 1866, including a number of each of the types then in use. These sections when figured out gave an average percentage of the total metal used in the

rails for the several parts as follows: Head, 47·67 per cent.; web, 19·08 per cent.; base, 34·25 per cent. By an examination of the percentages on Fig. 43 we find that they do not differ by more than 1 per cent. from the average of the forty-five sections.

These two rails continued in use up to the present time, 1907, as the P.R.R. standard rails, but it begins to look now as if they would be superseded by the new sections with a heavy base that are now beginning to come out. As yet none of them have been rolled, but there have been several of them published, and I have been told that the P.R.R. Co.'s engineers are working on new sections with the heavy base for the 85 and 100 lb. sections.

In the year 1893 what probably was the most popular rail that ever came out was introduced by the American Society of Civil Engineers. They soon became known as the A.S.C.E. rail. In the year 1885 this Society appointed a committee to consider and report at a future meeting on the proper relation to each other of the rail head and car wheels. And in 1890 this committee was supplemented by a larger one, retaining a number of the original members of the 1885 committee.

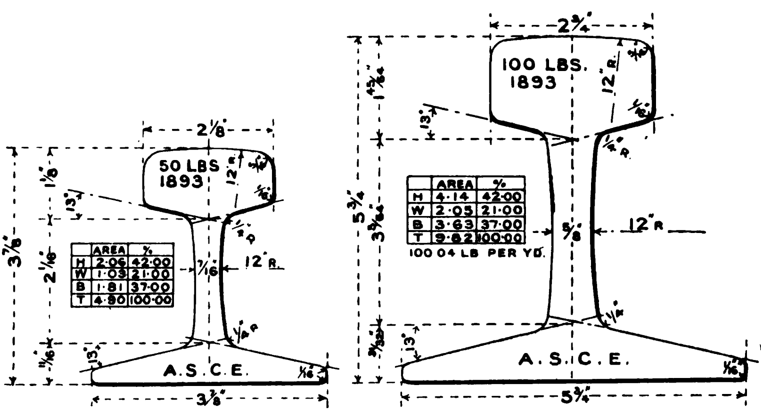


Fig. 44.

It has been a very interesting and instructive study to read over the reports of this committee, as submitted to the Society during the eight years they were at work on this problem.

At the 1900 meeting, when the later committee was appointed, one of the members, Mr. E. S. Morison, moved that each member be requested to prepare a design for a series of sections, these sections to be prepared regardless of any former instructions, and to be transmitted to the secretary by the 1st of December of that year. This resolution was adopted. And at the next meeting of the Society ten sets of sections were presented, and from these ten sets the sections as shown by Fig. 44 were produced, which are the 50 and 100 lb. sections of the A.S.C.E. standard rails.

There was considerable difference in the ten sections submitted; it would be of interest to write them out, but space will not permit. See Report for the year 1893.

After the adoption of the A.S.C.E. in 1893 the large number of different types and sections began to decrease, and from that time to 1907 there have not been a great many new sections brought out. What have come out were close imitations of patterns that have already been shown. For that reason I have not made any record of them, but go direct to the latter year, 1907, when the new sections with the heavy base came out.

This paper would not be complete without some mention of the cause which led up to this radical change in the form of the rail section. During the years 1900–1 and 2 the railroads were having a great deal of trouble with rail breakage in the track, and with the rail wearing out very rapidly. This caused great dissatisfaction and the matter was soon taken up by the different mechanical and engineering societies, who along with the railroad men began a crusade about 1902 for a better rail. In 1902 the A.S.C.E. started this reform by appointing a committee to investigate the causes for the above conditions and was followed by several of the other societies; these committees at once began their investigations and brought out many interesting facts as regards the subject. The labour of the several committees finally resulted in the adoption of the sections as shown by Figs. 45, 46.

The situation at this time is largely a repetition of the past history of the rail and its development. That is, the speed and weight of our railroad traffic has overtaken the enduring powers of the rail, and we must now as in the past improve the rail to a

point where it will withstand the largely increased work imposed upon it by the speed and weight of our railroad traffic. This improvement must come either by a better quality of material, such as when the Bessemer steel rail superseded the iron rail, or by a better disposition of the material we now have in the design and weight of the rail.

We find from reading the reports of the several committees that there was quite a diversity of opinion in regard to the change that should be made in the form of the rail. And it is possible, before this problem is finally settled to the satisfaction of all the parties concerned, we may revert back to a section somewhat on the side of the bullhead rail on Fig. 28. This would eliminate the broad thin base which seems to be the most serious fault found with the rail as now rolled.

The first of the new designs of rails with the heavy base was brought out by the Pennsylvania Railroad Co., who on September 20, 1907, adopted the 85 and 100 lb. sections as shown by Fig. 45. These two sections were designed by the engineers of that company, and were intended to take the place of the 85 and 100 lb. sections shown on Fig. 43.

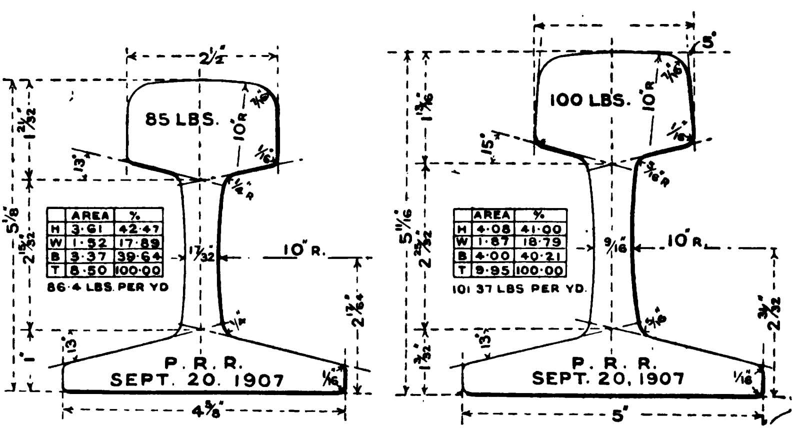


Fig. 45.

The first of the new designs to be rolled was the 85-lb. rail, Fig. 45, at the Maryland Steel Co. Works, Sparrow's Point, Md., on October 26, 1907. On that date there were three heats—

about 40 to 45 tons—rolled for a trial and for the purpose of obtaining some of the rails for testing purposes.

They rolled well and withstood some very severe tests.

About the 1st of December 1907 the Maryland Steel Company received orders to roll 2000 tons of the 85 lb. and 4000 tons of the 100 lb. rail (Fig. 45). Both of the sections proved to be about all that could be expected of them in regard to their working in the mill.

In the year 1907 the American Railway Association appointed a committee on rails. This committee reported in October 1907, proposing two series of rail sections consisting of 60, 70, 80, 90, and 100 lb. sections, one series A and the other B, as shown on Fig. 46.

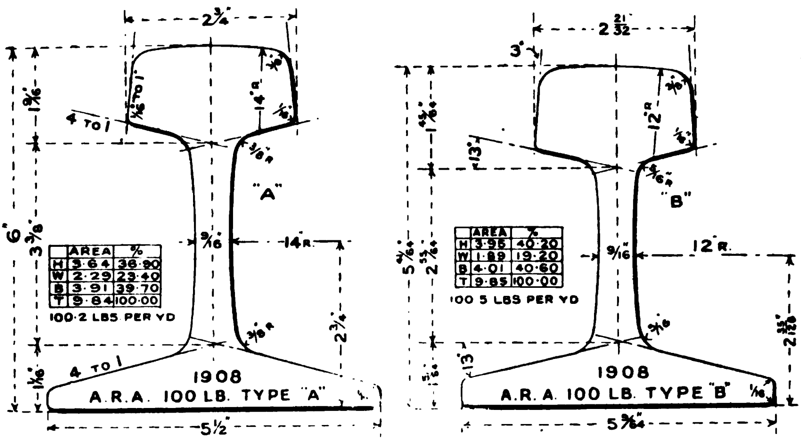


FIG. 46.

These sections were adopted as recommended by the committee on April 22, 1908, and are known as the "A.R.A." standard rails A and B. The A sections are a modification of the P. H. Dudley rail, No. 2, Fig. 42; the B sections a modification of the A.S.C.E. rails, Fig. 44.

I do not know that there were any of them rolled during 1908, but in the early months of 1909 they began to come into use quite freely.

These two sections and the two P.R.R. rails, Fig. 45, give a fair representation of the changes which have been given to the

shape of the rails since the railroads began the crusade for a better rail, about the year 1904. But if the railway men and the rail-makers do not take a firm hold upon and control the situation we shall no doubt be afflicted with an epidemic of new rail sections such as occurred previous to the coming out of the A.S.C.E. rail in 1903.

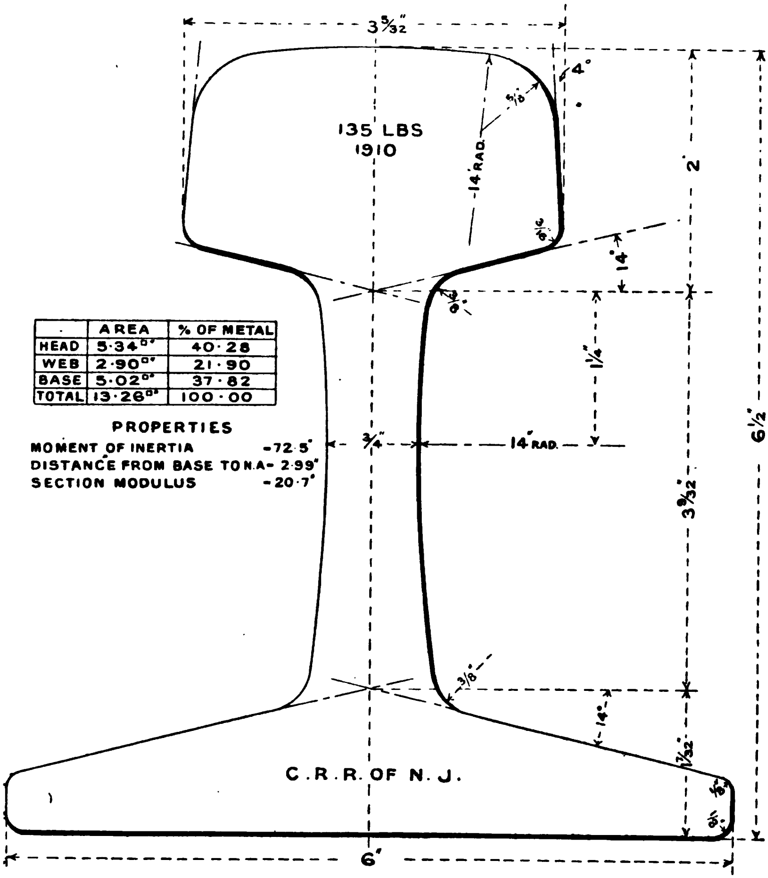


FIG. 47

With regard to the need of a heavier rail, which became apparent, owing to the increased weight of traffic, on the principal railways of the United States, the 135-lb. rail shown in

Fig. 47 was designed about 1910 for the Central Railroad of New Jersey.

During this year, 1910, several thousand tons of this rail were rolled, and laid in the tracks of this road. And other roads are beginning to see that it will soon be necessary to increase the weight of the rail.

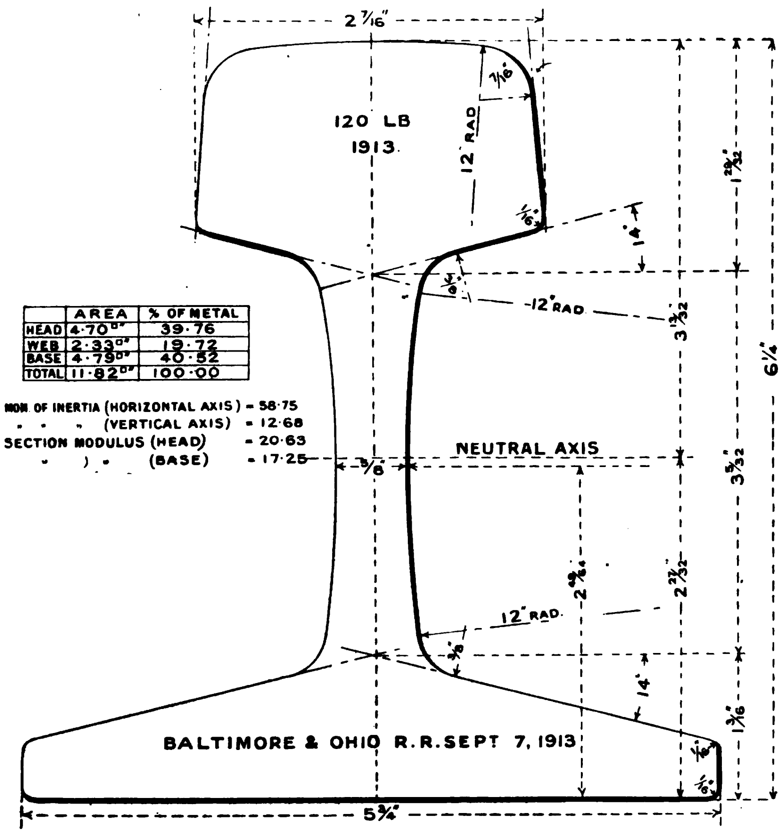


FIG. 48.

As a further indication that the rail section is destined to increase in weight, see section shown above at Fig. 48. This is a new 120l-b. rail for the Baltimore and Ohio Railroad Co. This section was rolled at the Maryland Steel Company's Works, Sparrow's Point, Md., on September 7, 1913.

The two rail sections shown below are the first and last tee rails made, covering a period of about 85 years. The small rail drawn in the head of the large one is the first rail rolled with a head, and was made in England between 1820 and 1825. First used on the Stockton and Darlington Railway, which was opened for traffic September 1825.

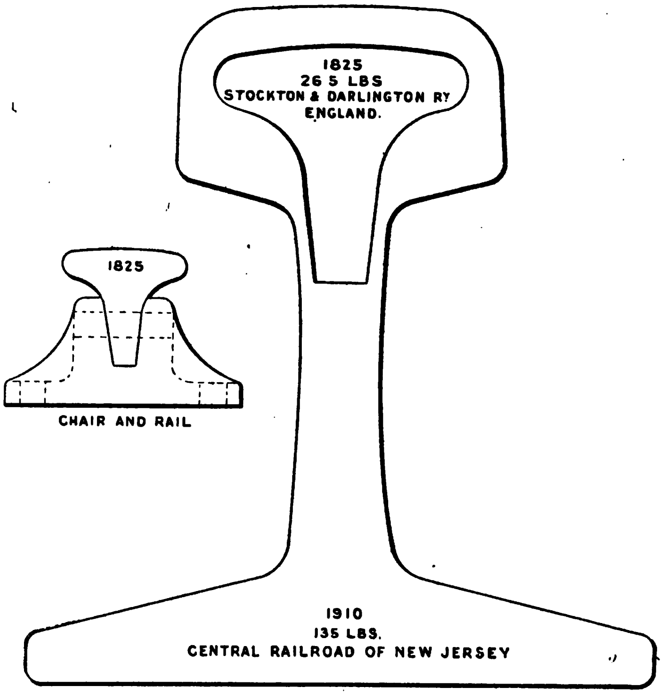


FIG. 49.

The large rail, 135 lb. section, is the last development of the tee rail. This rail was rolled at the works of the Pennsylvania Steel Co., Steelton, Pa., in the spring of 1910. First used upon the Central Railroad of New Jersey in 1910.

NAMES AND TITLES OF THE RAILS AS THEY CAME OUT.

It has proved quite a task to classify and give to the early rails their proper titles, as there are many conflicting statements in respect to the names given to the different types of rails by the early writers as they came out. I have endeavoured to get the names correct as far as possible.

The first rails, as we know, were wooden. The early wooden railways were called tramways, this name coming from a Mr. Outram, who was extensively connected with the early roads, the transition from Outram being easily made.

The first iron rails were of cast iron, cast in the form of flat bars, and were called plate rails; hence the English railway term, plate-layers (see Fig. 5).

Later, when flat rails were rolled from malleable iron, they received the name of strap rails (see Figs. 15 and 17, Figs. 6, 7, 11, and 12 showing some of the early cast iron tram or flat plate rails).

The next rails to come into use were the cast iron edge rails (see Figs. 8, 9, 10, 13, and 14). Later, when edge rails were rolled from malleable iron, they were first given the shape as shown on Fig. 19, No. 1, and the name given to them was tee rail. This name continued in use until the double rail, Fig. 28. This rail was at first called the double tee, and to distinguish the first rails the name was changed from tee to the single tee. The name double tee did not last very long, and the two rails on Fig. 28 soon became known as the double-head and bullhead rails, which names have continued to the present time.

The rail shown on Fig. 21 is known in history as the Birkenshaw fish-bellied rail.

The rails on Figs. 24, 32, 33, 36 are examples of the tee rail, as we now understand the term. These are all early rails. Fig. 41 shows some of the later tee rails when these rails first came out, and for a number of years after they went by the name of the H rail. This title was frequently given to the double-head rail by the early writers, which made it quite difficult at times to distinguish what type of rail they were referring to. Figs. 32 and 33 show

some examples of what are known in railway history as the pear-head rail, and on Fig. 34 some of the compound rails. These two types come under the general name of tee rail. In England, rails of this pattern are known as the flat-bottomed rails.

On Figs. 26, 27, and 30. These rails are known as the U or bridge rail, the name coming from the custom of laying rails of this type upon longitudinal sills which, when resting upon cross sleepers, give to the roadway somewhat the appearance of an extended bridge.

There have been in the past, as well as at the present time, a great many other names given to the rail as with the early rails. We find the Jessop, Stephenson, Birkenshaw, Clarence, and Stevens, and later, the Welch, Chanute, Dudley, Hunt, A.S.C.E. &c. But the names as given above, as wood, plate, strap edge, single tee, double tee, double-head, bullhead, H rail, bridge rail, and the tee rail, cover all of the various forms and types of rails that have been in use upon the steam railroads. At this time, all of them, except the double-head, bullhead, and tee rails, have gone out of use.

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CORRESPONDENCE.

Mr. FREDERICK MILLS (Managing Director of the Ebbw Vale Company) sent the following communication :

Mr. Graham (Steelworks Manager at Ebbw Vale), in connection with the reference on p. 258 to the Ebbw Vale Ironworks, interviewed Mr. Matthew Gower, who was a heater in the mill at Ebbw Vale at the period mentioned. Mr. Gower is eighty-two years of age, therefore in 1857 his age was twenty-two. He says he remembers the rolling off of the steel rail, but cannot give dates.

There were two mills (Nos. 3 and 5) rolling rails—the former, light sections, and the latter, the heavier. Gower worked in No. 5 as a mill furnaceman.

He does not recollect Mr. Mushet, but remembers the treatment to which steel ingots or blooms had to be subjected, and the difficulties in rolling off owing to the hardness, as compared with iron.

He remembers that the first rail was a double-head section, that it rolled off successfully, and that there was a big hurrah! when it left the rolls. He states that there was a good deal of prejudice towards steel, as it was deemed it would be bad for labour.

Mr. Gower says it was a bloom which he treated for rolling off, and not an ingot. He says the ingot was first forged under a steam-hammer at Ebbw Vale. John Kenvyn, John Lewis, and Robert Roberts were working at the hammer.

He does not know anything about the destination of the rail, but can remember strangers coming to experiment.

Mr. John James was head manager, and Mr. John Lee's father was roll turner at the time.

He remembers the talk at the time of the reputably successful iron bridge rails rolled at Pentrebach under Mr. Anthony Hill and laid down between Abergavenny and Hereford, and how it was said that no rail, steel or other, could be made to beat the former in quality.

He confirms the story of the book, regarding the stalling of the engine in the rolling off of the bridge rail.

REPLY OF MR. J. N. KILBY TO THE DISCUSSION ON HIS PAPER (p. 69).

The author wrote, in reply, thanking the various members for kindly taking part in the discussion of his paper.

He wished to express his best thanks to Mr. J. E. Fletcher for what he thought was a useful addition to the paper.

In reply to Dr. Hatfield, it was an unintended omission on the author's part not to have referred to the 1902 and 1904 papers by Dr. Hatfield and Professor McWilliam. He also wished to add that he had not forgotten those papers.

In referring to the question of the influence of included particles of slag upon ordinary carbon steels, and mentioning the comparative slight influence upon the "physical tests called for in those steels," he implied that the tests asked for upon such steels (ordinary billets, rails, springs, &c.) did not materially suffer in consequence of the presence of such inclusions referred to. Certainly such steel would be better free from slag particles; (see Dr. Hatfield's extract from the paper) "the presence in ordinary carbon steels of this finely divided or emulsified solution of slag *is just as little desired* as in the case of special steel." The data upon which the statement was made in the paper was based upon the fact that all ordinary carbon open-hearth acid steels suffered more or less from slag inclusions, but that failures and rejections were more rare than in the case of special steels. Granted that where the carbon steel was used for extremely particular work where high quality must prevail, slag inclusions would be as objectionable as in a special alloy steel.

As to the term "occlusion" the author agreed that "inclusion" might be better.

With regard to Mr. E. H. Saniter's point referring to a sketch at the end of the paper of an ingot cast narrow end up, which appeared not to be comparable to the remarks in the paper dealing with casting details, the author wished to state that the sketch was included merely to show the danger of segregated steel being present in the tire and causing failures. He also agreed that a sound ingot might yield unsound forgings or billets from causes arising during manipulation of the ingot.

In reply to Mr. Service, the author agreed that pyrometry upon sound lines was more than desirable in steelmaking, and he would be the last to adhere to what Mr. Service called "experience and eye method." Heat treatment of steel, and the value of pyrometry in that branch of the trade, was never hinted at in the paper; also measurements of such temperatures were valuable only because of their accuracy. He would like to refer to the figures given by Mr. Service of casting tem-

perature, and he took them to show the temperature of the steel either leaving the furnace or the ladle, and therefore failed to see where those figures supported his argument relative to furnace control. He referred to the value of a pyrometer as an instrument to measure the actual furnace and bath temperatures in a sufficiently accurate manner to control the process. The small amount of data given by Mr. Service implied that nickel-chrome steel, in order to yield sound forgings, was better cast on the warm side, with which opinion he could hardly agree without more enlightenment. Taking the figures in the first and second columns, they apparently showed that a difference in temperature of from 5° to approximately 20° C. influenced the defects in a remarkable degree. Was Mr. Service certain of those slight differences in temperature, and sure that such differences were alone responsible for the yields? Before accepting the figures the teeming speeds, size and weight of ingots would have to be included.

Relative to the use of added slag, the author did not contend that such additions add *silicon* to the charge, and the 25 per cent. of silicon referred to was termed "available silicon for conversion into silica (SiO_2)"; hence the addition of slag to make up any deficiency. Ferro-silicon would certainly be better than slag, but the cost was too great.

He agreed with Dr. Desch that an ideal steel would be one free from slag particles, and would state that, whilst bad for all steels, ordinary carbon steels did not suffer so greatly as did special and alloy steels. He would like to refer to the reply to Dr. Hatfield upon that point. He entirely agreed with him, in variance to Dr. Rodgers, that there was not sufficient known of the reactions of the acid open-hearth, and that certainly opened a big field for research.

He agreed with Dr. McCance that temperature influenced the position of the slag at the melted stage, but did not think temperature alone would overcome the conditions referred to in charges working with a thin open slag and coming to boil with little or no ore. He had taken charges which had been worked from commencing to charge to tapping in ten hours, a time which Mr. McCance would agree did not allow of what he termed "cold melting." At any rate, that speed of working necessitated quicker and hotter melting than that known by the author at most British steelworks. The danger of cold melting was referred to fully in the paper, and also the means of quick, hot melting was emphasised. The author would like more details supporting Dr. McCance's figures of rejections in reference to slags taken thirty minutes after the melted stage.

The addition of slag from previous heats was to be made during charging operations, and not during melting or at the melted stage. The necessity for a "fluid open slag" to ensure a good boil did not prove the utility of a slag very high in oxide of iron and proportionately low in silica (SiO_2). A "fluid open slag" could be obtained by judicious use of limestone in the early stages, the great changes taking place in the slag supporting the contention of quick reaction and one which was

claimed in the paper. Table A given by Dr. McCance did not show that oxidation was equally rapid without lime additions. He compared it with Fig. 5 in the paper, and it would be seen that the composition of the slag, as shown in Fig. 5, reached the stage referred to one hour earlier than that given in the diagram of Dr. McCance.

In reply to Mr. Williams, when speaking of casting speeds being even throughout the filling of the ingot, that point was referred to in the paper, p. 81, and was undoubtedly of the greatest importance. All the small ingot teeming times given in the paper were taken only to just below the feeder head. It had been the practice of the author for over ten years when taking teeming speeds to base such figures only to such points as where the ingot was "fed." Also it had been considered of the most vital importance that the ingot should be filled evenly from the bottom to the top, each ton of steel requiring a certain time, which was governed by the size of the ingot and its weight.

REPLY OF MR. LAWFORD H. FRY TO THE DISCUSSION ON HIS PAPER (p. 119).

(*Received too late to include at the end of that discussion.*)

Mr. Fry wrote in reply to the discussion that he was glad that Dr. Desch agreed with him as to the necessity of accurate description of the rate of cooling in dealing with the properties of heat-treated material. Dr. Bone had raised an interesting point, and one which deserved further consideration in the future. It was true that the pyrometer used did not at all times indicate the mean temperature of the whole object. In each class of axle, however, the temperature being always taken at the same point was some measure of the mean temperature. At the beginning and at the end of the quench the pyrometer temperature was practically the mean temperature, and at no time during the quench was there any great difference between the mean temperature and the temperature measured. Before quenching the object was uniformly heated so that the temperature was the same in all concentric shells referred to by Dr. Bone. On quenching the shells were cooled progressively from the outside, and as this took place there was the flow of heat described by Dr. Bone from the higher centre temperature T to the lower peripheral temperature t. Thus the action of quenching produced a temperature gradient sloping from the centre to the outside of the object. This temperature gradient gave the exterior shells a tendency to shrink as compared with the hotter interior shells and thus set up quenching strains and stresses. The more rapid the cooling the greater the temperature gradient and the greater the stresses due to the differing shrinkages.

In considering the differences between the mean mass temperature and the temperature measured in the author's experiments, it should be borne in mind that the temperature gradient in the metal was very much less than the temperature gradient between metal and quenching fluid. The heat was transmitted through the metal very much more readily than it was transferred from metal to fluid, so that for a given rate of heat flow there was a comparatively slow fall of temperature from the centre to the outside of the object and an abrupt fall from the outer skin to the quenching fluid. The comparatively easy gradient through the object made it certain that the mean temperature was not very different from the measured temperature, and that the latter gave a reasonably good idea of the rate at which the piece as a whole cooled.

Mr. Fry regretted that he could not give exact figures for the drop in temperature along the diameter, but experiments on that subject by one of his colleagues were under way and would, he hoped, soon be available for publication.

The usual obituary notices of deceased members, the list of additions to the Library, and the list of Exchanges will appear in the next number.

SECTION II.

NOTES ON THE PROGRESS OF THE HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

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In the preparation of these Notes the Editor has been assisted by L. P. Sidney, Assistant Secretary, and others.

IRON ORES.

CONTENTS.

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I.—*OCCURRENCE AND COMPOSITION.*

Origin of Iron Ore.—R. B. Sosman and J. C. Hostetter (*Paper read before the Geological Society of Washington,* March 22, 1916) have observed, in studying the natural oxides of iron, that some of these can be separated magnetically into fractions. Ferric oxide and magnetite have been shown to form a series of solid solutions in which the percentage of FeO increases continuously from zero to 31·03, which is the percentage in magnetite. The oxides become increasingly magnetic as the percentage of FeO increases. Analyses and magnetic measurements on a cross-section of an Elba crystal showed that the magnetic susceptibility and percentage of FeO vary, not irregularly, but continuously, being highest at the base and lowest at the free-growing tip of the crystal. The crystal is therefore zoned with respect to its FeO content. The physico-chemical conditions which could bring about such a zonal growth are considered.

R. B. Sosman (*Address to the Chemical Society of Washington,* January 11, 1917; *Journal of the Washington Academy of Sciences,* 1917, vol. 7, pp. 55–72) discusses some problems of the oxides of iron. A simple magnetic test combined with a determination of the ferrous iron permits certain preliminary conclusions as to the origin of many natural oxides of iron. But there are other magnetic properties which may be expected to vary with the composition and constitution of the oxide. Apparatus and methods have been devised for the study of the magnetic, physical, and chemical properties with a view to their correlation.

Iron Ore in Cumberland.—A description of the new iron ore mine of the Millom and Askam Company is published (*Iron and Coal Trades Review,* December 1916, vol. 93, p. 701), with special reference to the

sinking operations. The Florence Pit, Ullbank Mines, is situated about one mile distant from Egremont Station. The site of the shaft, 17 feet in diameter in the clear, is at a point where the limestone meets the conglomerate fault and, as a consequence, some of the richest ore in the district has been tapped in the various boreholes. The deposit in some cases proved upwards of 140 feet in thickness.

Iron Ore in Japan.—It is reported (*Journal of Industrial and Engineering Chemistry*, November 1916, vol. 8, p. 1067) that, owing to the greatly increased demand for iron and steel, the Japanese Government has been investigating sources of ore supply in Japan, and it appears, from the report recently issued, that the main source of supply is the Kamaishi mine, the deposit of magnetic ore there being estimated at 35,000,000 tons. Deposits of similar ore are estimated to total between 5,000,000 and 6,000,000 tons from mines in the provinces of Rikuchu, Echigo, Iwaki, Iwashiro, Kozuke, Yamato, Harima, and Mimaska. Deposits of red iron ore, estimated to total about 30,000,000 tons, are located in the provinces of Echigo, Rikuchu, Tosa, Hyogo, Rikuzen, and Izumo. Brown iron ore deposits, believed to total 10,000,000 tons, bring the estimated aggregate total to about 80,000,000 tons for the islands alone.

Magnetic Iron Sands in Canada.—P. E. Dulieux (*Metallurgia Italiana*, December 1916, pp. 758–767) gives an account of the occurrence of the magnetic sands in the Province of Quebec, and of the magnetic concentration of titaniferous magnetites and ilmenite.

Iron Ore in the United States.—W. G. Imhoff (*Blast-Furnace and Steel Plant*, December 1916, pp. 553–555) describes the Marklesburg iron mine, situated on Tussey Mountain, about three miles almost due north of James Creek, Pennsylvania. This fossil ore bed has been mined for more than forty years. The rocks belong to the same formation as the Clinton ores of the Alabama district. The ore bed pitches steeply. Typical analyses of the ores are as follows :

	Per Cent.	Per Cent.
Iron	44·25	54·95
Silica	27·91	9·69
Alumina	2·66	...
Lime	0·22	1·13
Magnesia	0·26	...
Phosphorus	0·68	0·469
Sulphur	...	0·12

About 500 tons a month is the output, and some account is given of the methods of working.

Iron Ores of the Adirondack Region.—F. S. Witherbee (*Paper read before the American Iron and Steel Institute*, October 27, 1916; *Monthly Bulletin*, October 1916) observes that the ores of the Adiron-

dack district, near Port Henry, on Lake Champlain, are undoubtedly the highest grade ores shipped from any district in the United States. The iron content is guaranteed from 60 to 65 per cent. and one special grade has a guarantee of 71 per cent. The phosphorus runs from 0·005 to 1·50 per cent., and probably 60 per cent. of the known deposits are within the Bessemer limit. The reserves in the district are estimated at 1,100,000,000 tons.

Iron Ore in Africa.—Iron-ore deposits in the German colonies of West Africa (*Iron Age*, December 1916, vol. 98, p. 1409) are reported as large by a French authority. In Togoland the iron ore is hæmatite, containing 89·51 per cent. of iron oxide, 9·47 per cent. of infusorial earth, 0·24 per cent. of alumina, 0·16 per cent. of manganese oxide, and the phosphorus content is equivalent to 0·30 per cent. of phosphoric acid. The deposits probably represent 20,000,000 gross tons. In the Kamerun district an abundant deposit analyses 42·29 per cent. of metallic iron ; manganese, 0·35 per cent. ; phosphorus, 0·17 per cent. ; and infusorial earth, 12·26 per cent.

Manganese Ore.—H. K. Scott (*Bulletin of the American Institute of Mining Engineers*, No. 120, 1916, pp. 2222–2228), in a communication on the paper by E. C. Harder on manganese ores, describes the ore deposits of Russia, India, Brazil, and Chili, and their economic value.

Manganese Ore in the Sinaï Peninsula.—J. Ball (*Survey Department, Egypt ; Geography and Geology of West Central Sinai*, pp. 1–219) reports on the geology of the Sinai Peninsula, and refers to the extensive manganese deposits which are now being worked there.

Manganese Ore in Newfoundland.—N. C. Dale (*Geological Society of America*, Bulletin, 1914, vol. 25, pp. 73–74) describes the occurrence of manganese ore along the north shore of Newfoundland, on Conception Bay, on Smith Sound, on Trinity Bay and on Placentia Bay. The manganese minerals and interbedded bands of jasper form zones 20 to 30 feet wide in a group of red and green shale and limestone of Lower Cambrian age.

Manganese and Manganiferous Ores in the United States.—D. F. Hewett (*U.S. Geological Survey, Mineral Resources*, 1915, Part I. 1–4, pp. 29–43) says that the year 1915 was eventful in the manganese industry of the United States. There was a great increase in the production of each variety of ore, although the total is still far below the country's need. New deposits that may become important sources of production have been explored in several States and old mines have been re-opened. In the manganese alloy industry several new producers of ferro-manganese have entered the field, and several companies that

have not attempted to make alloys for some years have again become producers. The production of manganese ore during 1915 was 9709 tons, as compared with 2635 tons in 1914 and 4048 tons in 1913. The production of manganiferous iron ores (in 1915) was 801,290 tons, most of which came from established sources. Of this quantity 69,416 tons contained more than 15 per cent. manganese, and most of this was used in the manufacture of low-grade ferro-managnese, whereas those ores which contained less than 15 per cent. manganese were used largely in making high manganese pig iron. There are also included a discussion of general sources of manganese, data as to the production, imports, and world trade conditions in this industry, and interesting metallurgical sections regarding manganese ores, manganiferous zinc residuals, ferro-manganese, and spiegeleisen both in America and elsewhere.

D. F. Hewett (*U.S. Geological Survey, Economic Geology*, Bulletin 640–C, 1916, pp. 37–71) reports on some manganese mines in Virginia and Maryland, in particular the Piedmont, the Midvale, the Lyndhurst, the Kendall & Flick, the Happy Creek, and the Dargan mines. Four of these mines, together with the Crimora and Evington mines, have produced practically all the manganese ore mined in Virginia in the last five years. The occurrence of the ores is described, the chief of which are psilomelane, containing 50 to 57 per cent. manganese, manganite, containing 62·4 per cent. manganese, and wad with 30 to 42 per cent. manganese. During the five years 1910 to 1914 the home production of manganese ore was only 1 per cent. of the imports, but efforts to increase the home production have been made since 1915.

Manganese Ore in Costa Rica.—According to a report of the department of commerce (*Iron Trade Review*, vol. 60, 1917, p. 424) one manganese mine is in operation in Costa Rica. The mine began shipping in May 1916 and is now sending out about 300 tons per month, all in bags. It is making preparations to instal an equipment of docks, furnaces, &c., with a capacity of 3000 to 5000 tons a month. This equipment will probably be completed by July 1, 1917. Facilities for loading ocean steamers from its own docks are to be provided. Its port will be about two miles south of Braxilito, which is a little north of Morro Hermoso, on the Pacific side, considerably north of the Pacific port of Puntarenas. The plant is at Playarreal, Guanacasto, Costa Rica. The ore is given as averaging 55 per cent. metallic manganese, or for chemical purposes, 80 to 83 per cent. manganese dioxide. Other claims have been selected, but no other company has begun operations.

Chromite.—J. S. Diller (*U.S. Geological Survey, Mineral Resources*, 1915, Part I. 1, pp. 1–6) reports on the occurrence, production, and imports into the United States of chromite, giving notes on its uses.

Some notes on chromium and chromiferous ores are published

(*Engineering*, January 12, 1917, vol. 103, pp. 30–32) relating to the characteristics of chromite, its occurrence and production, with an account of the uses of chromium. An analysis of a chromium-cobalt-tungsten high-speed alloy is given.

Molybdenite.—H. H. Claudet (*Transactions of the Canadian Mining Institute*, 1916, vol. 19. pp. 124–130) gives notes on the occurrence of molybdenite in Norway. The most important discovery is at Knabeheien near Kvinas Valley, north of Flekkefjord. The ores are treated by the Elmore vacuum process, and commercial results have been obtained with ore as low as 0·4 per cent. MoS_2, which has been concentrated up to 70 to 75 per cent. MoS_2 in one operation. An increased production in Norway can be confidently expected.

H. E. Wood (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, pp. 106–123) demonstrates that the metallurgical problem of the successful concentration of molybdenite is an extremely simple one, his experience being obtained by the milling of over 200 tons of molybdenum ores both simple and complex. The operations and plant, and the conditions affecting capacity, are described in detail.

According to E. C. Andrews (*New South Wales, Department of Mines, Mineral Resources*, No. 24, 1916, pp. 1–199), all the molybdenite deposits of New South Wales are associated intimately with granites of varying ages. The great majority of the more important deposits consist of pipes. The actual amount of molybdenite contained in the deposits of Yetholme, Booroolong, Glen Eden, Tantawanglo Mountain, Laura Creek, and other places is very great, but no mining operations have been conducted on such deposits, and it would appear that they could be worked only at a profit under excessively cheap conditions, coupled with the greatest skill and economy. The pipes consist mainly of quartz, pegmatite, silicified granite, or granite with much secondary mica or garnet.

F. C. Calkins (*U.S. Geological Survey, Economic Geology*, Bulletin 640–D, 1916, pp. 73–76) has investigated an occurrence of molybdenite in San Diego County, California. The mineral occurs in an aplite dyke, and is very unevenly distributed through the rock. A large sample of the rock is said to have assayed about 2 per cent. of molybdenum, but the field examination shows that as a whole the content cannot exceed a small fraction of 1 per cent.

Molybdenum and its Uses.—H. Fleck (*Colorado School of Mines Quarterly; Iron Age*, vol. 98, 1916, p. 1117) deals with the history, geology, and metallurgical treatment and uses of molybdenum. The ammonium salt and the oxides are the compounds most used, the former in analytical operations and as a fire-proofing material, and the latter as a self-hardener in steel. Molybdenum is more effective in combination with chromium than when used alone. Nickel-molybdenum alloys are also used. The tensile strength of molybdenum

wire is given at 200,000 to 270,000 lb. per square inch, as compared with 480,000 to 580,000 lb. for tungsten. Molybdenum wire has been used for winding electic furnaces and for thermocouples, and the oxides are also used for colouring purposes and as a preservative to smokeless powders.

Nickel Ores.—An account is given of the occurrence and utilisation of nickel ores. The Canadian nickel ores and those of New Caledonia are described and analyses are shown (*Bulletin of the Imperial Institute*, 1916, vol. 14, No. 2, pp. 228–253).

F. C. Calkins (*U.S. Geological Survey, Economic Geology*, Bulletin 640–D, 1916, pp. 77–82) reports on an occurrence of nickel ore in San Diego County, California. The ore consists mainly of pyrrhotite, but contains pyrite, chalcopyrite, and an iron-nickel sulphide. The nickel percentage is reported to range from 2·94 to 22·95. The higher figure is, however, not confirmed. The geology of the occurrence and the probable origin are discussed.

C. F. Tolman, Jun., and A. F. Rogers (*Engineering and Mining Journal*, 1917, vol. 103, pp. 226–229) have carried out a complete microscopic examination of the Sudbury nickel ores with the polarising and reflecting microscopes, and have thereby positively determined the relative ages of the rock minerals and the ore minerals. The results of their investigations reconcile the two antagonistic views in regard to the origin of the ores. They confirm the conclusions of the opponents of the magmatic theory that the ores were formed after the rock-forming silicates, but, on the other hand, agree that the ores are not hydrothermal, but for different reasons than advanced by those investigators. Detailed microscopic study has shown among other things that the typical hydrothermal minerals are of later origin than the ores.

Nickel in Italy.—L. Parodi (*Metallurgia Italiana*, May 1916, vol. 8, pp. 355–368) gives an account of the metallurgy and uses of nickel, in which reference is made to the occurrence of nickel in the upper valley of the Sesia on the southern spurs of Monte Rosa. The mineral occurs in the form of pyrrhotine. Nickeline (arsenide of nickel) is also found mixed with galena and other minerals containing sulphur in veins enclosed in the Silurian schists of Sardinia. From 1871 to 1878 the ores of Valsesia in Italy were regularly worked and smelted at Rocca Pietra, the smelting process being fully described. The ores of New Caledonia and Canada and their method of treatment are referred to.

Cobalt.—Some account of the occurrences and utilisation of cobalt ores is given (*Bulletin of the Imperial Institute*, 1916, vol. 14, No. 3, pp. 417–437).

Tungsten in Australia.—It is stated (*Electrician; Journal of Industrial and Engineering Chemistry*, January 1917, vol. 9, p. 99) that eight squares miles of wolfram-bearing ore have been located at Hatch's Creek, North Territory, Australia. Developments in this direction in Australia will be watched with close interest in view of the fact that previous to the war the extraction of tungsten from wolfram ore formed an important German monopoly.

A report issued by the Department of Mines of South Australia (*Iron Trade Review*, 1917, vol. 60, p. 424) shows that the recent increase in the demand for tungsten minerals has attracted a number of prospectors to the Callawonga Creek district.

Molybdenum and Tungsten; Chillagite.—Some notes on the characteristics and composition of chillagite are given (*Records of the Geological Survey of New South Wales, Department of Mines*, 1916, vol. 9, Part 3, pp. 171–173). Analyses of carefully selected specimens show the crystals to consist of:

	Per Cent.
PbO	54·36
WO_3	24·24
MoO_3	19·44
Gangue	0·14

The mineral, containing, as shown above, lead, tungsten, and molybdenum, was first recorded in 1911, a specimen having been discovered by A. J. Ullman, of Chillagoe, in that year.

Ores of Metals Employed in the Iron and Steel Industries.—F. L. Hess (*U.S. Geological Survey, Mineral Resources*, 1914, Part I. 25, pp. 923–946) reports on the production, imports, exports, composition, and technology of cobalt, molybdenum, nickel, titanium, tungsten, radium, uranium, and vanadium, with notes on their uses.

Recent developments in the metallurgy and use of molybdenum in Canada are referred to by A. Stansfield (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, p. 134).

Monazite and other Thorium Minerals in Ceylon.—The results of a search conducted by the Imperial Institute for thorium-containing minerals in Ceylon are reported (*Bulletin of the Imperial Institute*, 1916, vol. 14, No. 3, pp. 321–369). A number of known deposits were examined and minerals were analysed for their thorium content, the analysis being stated. No reference is made to the economic value of the occurrences.

Meteorites.—J. C. Brown (*Memoirs of the Geological Survey of India*, 1916, vol. 43, Part II., pp. 149–287) has compiled a descriptive catalogue of the meteorites comprised in the collection of the Geological Survey of India.

II.—*IRON ORE MINING.*

Rock-Drills.—An illustrated description has appeared (*Engineering and Mining Journal*, 1917, vol. 103, p. 155) of a pneumatic drill-sharpening machine designed by the Denver Rock Drill Manufacturing Company, which it is claimed is not only economical in the consumption of air, but will also operate effectively with lower pressures than are required by other types. The clamping die cylinder is placed directly above the die blocks, which position is largely responsible for the effectiveness of the machine under low pressures. No air is exhausted on the down stroke of the ram piston, as the piston is returned to its upward position by two small constant-pressure pistons, and when the blow is struck with the ram or it is brought down for the purpose of holding the steel while dollying, the air in this constant-pressure cylinder is merely forced back into the pipe line. The dollying hammer is of the valveless type and exceedingly economical in air consumption. There is only a single air connection, consisting of a flexible hose, and as the machine exhausts into the hollow base, no exhaust pipe leading from the machine is required, and the exhaust is so muffled that it is hardly noticeable. The manufacturers are also developing a smaller model. The use of drill sharpeners to replace the laborious and slow hand methods is becoming more common practice, even in small plants.

Ore-Handling.—J. P. Griffith (*Minutes of Proceedings of the Institution of Civil Engineers*, 1915–16, vol. 202, pp. 323–347) reviews the progress in the development of ore and mineral handling appliances, with special reference to American practice. The Hulett system of unloading is described, among others.

M. E. Richards (*Blast-Furnace and Steel Plant*, June 1916, p. 288) discusses the mechanical devices in use for loading ore in underground mining.

The method of transporting iron ore from the Iron Knob, owned by the Broken Hill Proprietary Company, is illustrated and described (*Mining and Engineering Review*, September 1916; *Mining Magazine*, December 1916, p. 358). The ore is carried along the jetty on conveyor belts, consisting of a set of seven belts 36 inches in width and $\frac{3}{4}$ inch thick, which discharge from one to another until the end of the jetty is reached. The rated capacity of the belts is 1000 tons per hour, and this tonnage has been conveyed without difficulty.

Valuation of Metal Mines.—T. A. Rickard (*Transactions of the International Engineering Congress; Mining Engineering*, San Francisco, 1915, pp. 67–81) reviews the principles held to govern the methods of mine valuation. To value a mine for sale or purchase it is necessary to estimate its future profits, by ascertaining (1) the average yield per ton of ore; (2) the average cost per ton of ore (the difference

between (1) and (2) is the profit); (3) the tonnage available now; (4) the tonnage likely to be available in future years. The fourth item is the most important and most difficult to ascertain. Mines should not be appraised on the basis of an investment, but are only to be regarded as a wasting asset, which as a speculation may be profitable if worked intelligently.

III.—*MECHANICAL PREPARATION.*

Magnetic Concentration of Low-Grade Ores.—S. Norton and S. Le Fevre (*Bulletin of the American Institute of Mining Engineers*, No. 122, 1917, pp. 149–169) deal with the magnetic concentration of the low-grade ores of New York and New Jersey. The problem as a whole is one involving the ultimate utilisation of billions of tons of now worthless non-bearing rock, by producing therefrom 10 to 20 million tons of high-grade ore of 60 per cent. iron and upwards, annually. The Ball-Norton method is described and illustrated in full, and other methods are also described and compared with it. Both wet and dry methods are given. The charges are described as low.

Concentration of Tungsten-Molybdenum Ores.—A. J. Robertson (*Geological Survey of Western Australia*, Bulletin 64, 1915, pp. 55–63) deals with the concentration of tungsten-molybdenum ores. An ore from the Murchison Goldfields containing molybdenite 2 per cent., scheelite 10 per cent., wolframite 1½ per cent., and gangue 86½ per cent., was treated in the laboratory by flotation to recover the molybdenite, then by gravity concentration to obtain the tungsten minerals. It was found that crushing to 80-mesh caused sliming of the clayey gangue, the fine dust coating the molybdenite and preventing flotation. Better results were obtained with ore crushed to pass a 30-mesh screen, but it was not possible to obtain high-grade molybdenite by a single treatment. The best results were obtained by floating carefully sized material (30–40 mesh), screening the float through a 90-mesh screen, and rejecting the undersize, consisting mostly of gangue. The tungsten minerals were satisfactorily extracted from the 30-mesh flotation tailings by panning.

Preparation of Nickel Ores.—Some further notes on the metallurgy of nickel are published (*Metallurgia Italiana*, October 1916, vol. 8, pp. 605–609). Special reference is made to the Norwegian deposits, the character of the ore, and its treatment by the Hybinette process.

A. Lotti (*Metallurgia Italiana*, July 1916, vol. 8, pp. 429–432) gives some additional notes on the treatment of nickel ores in America.

IV.—*METALLURGICAL PREPARATION.*

Sintering of the Low-Grade Iron Ores of Ontario.—G. C. Mackenzie (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, pp. 148–150) describes experiments with the low-grade magnetic iron ores from the Bessemer mine in Central Ontario, by which a high-grade material has been successfully produced by magnetic concentration and by sintering the concentrates. The fuel used for sintering was charcoal breeze and charcoal flue-dust. The analyses of the Bessemer crude ore and the magnetic concentrates were :

	Bessemer Crude. Per Cent.	Concentrates. Per Cent.
Iron	43·9	67·51
Sulphur	0·3	0·11
Phosphorus	0·028	0·014
Insoluble	30·88	5·98

The method of sintering consisted in first giving the material an intimate mixing and then adding the necessary water, after which the mixture was sintered in a Dwight-Lloyd pan of the stationary type. The product, containing 66·5 per cent. iron, 0·023 to 0·044 per cent. sulphur, and 0·015 to 0·026 per cent. phosphorus, was tough and porous, and very suitable for use in the blast-furnace.

REFRACTORY MATERIALS.

Research on Refractory Materials.—A general discussion on refractory materials was held by the Faraday Society on November 18, 1916, at which Sir Robert Hadfield delivered an introductory address. Papers on the subject were contributed by F. J. Bywater on "Refractory Material"; J. W. Mellor on "Texture of Firebricks"; W. G. Fearnsides on "Application of Petrographic Methods to the Study of Refractory Materials"; R. Lessing on "Examination of the Texture of Unfired Refractories"; H. G. Colman on "Work of the Joint Refractory Materials Committee"; J. Allen Howe and A. Strahan on "Work of the Geological Survey on Refractory Materials"; T. Crook on "Work of the Imperial Institute in Connection with an Exhibit of Refractory Materials"; Cosmo Johns on "Silica as a Refractory Material"; A. Cliff on "The Manufacture of Refractory Materials"; E. P. Page on "Classification of Refractory Materials"; P. G. H. Boswell on "Properties and Resources of Refractory Sands in Great Britain"; E. Griffiths on "Thermal Conductivity of Materials Employed in Furnace Construction"; E. Griffiths and E. C. Griffiths on "A Carbon Tube Furnace for Testing the Softening Points and Compressive Strengths of Refractories"; H. B. Cronshaw on "Deterioration of Refractory Materials in the Iron and Steel Industries," and on "The Standardisation of Refractory Materials used in the Iron and Steel Industries"; R. B. Sosman on "The Common Refractory Oxides."

Composition of Refractories.—W. Donald (*Journal of the West of Scotland Iron and Steel Institute*, 1916–17, vol. 24, pp. 121–151) discusses refractories from the point of view of the manufacturer and the purposes for which the various known refractory materials are required. The properties and chemical combination of silica, lime, magnesia, alumina, ferric oxide, chromic oxide, zirconia, and other oxides are considered, and the percentage composition of oxides present in silicates, aluminates, and ferrates is given. Trials with dolomite and bauxite mixtures are described, and the conclusion concerning dolomite was that there was no material which could be added in any percentage ranging from 2½ to 50 per cent. that gave refractory basic bricks of good quality in the sense that the word "good" is applied to magnesite bricks. Dolomite bricks cannot be compared with magnesite bricks, as they are not able to stand transit, and have to be prepared at the place where they are to be used. With bricks of all kinds the greatest care should be taken not only in handling but particularly in storing. Any brick is injured by being stored in the open.

Influence of Chemical Composition on Behaviour of Fireclays.—J. L. Dickson (*Blast-Furnace and Steel Plant*, March 1916, pp. 119–120) writes that iron oxide is generally the most objectionable low temperature flux in a refractory clay. The alkalies are the most powerful fluxes, but are generally found in only small quantities in otherwise pure clay. The action of these fluxes upon the vitrification of bodies is noticeable at cone 1 (about 1150°C.) The oxides of calcium and magnesium are low temperature fluxes, but are not active until higher temperatures are reached than those required to flux the alkalies and iron oxide. Both oxides form easily fusible eutectics with silica and alumina, and dissolve the body of the ware in much the same way as the alkalies. These fluxes are dangerous in a clay in that their melting points are very close together. The fluxes are, however, of value to a clay in bonding the body, but must be present in very small amounts. The total acid fluxes (TiO_2 and P_2O_5) should be under 4 per cent. and never over. In bauxite the total basic fluxes (Fe_2O_3, CaO, MgO, K_2O and Na_2O) should never exceed 4 per cent. together. The total fluxes should not exceed 6 per cent. if the clay is to withstand high temperatures. The silica-alumina ratio is always below 1·50 in high-grade clays. Some notes on making bauxite bricks are given.

Properties of Fireclays.—J. W. Mellor (*Journal of the West of Scotland Iron and Steel Institute*, 1916–17, vol. 24, pp. 104–112) gave a lecture on some properties of fireclay. The composition of kaolinite is given and its time-temperature curve, also the time-temperature curve of Glenboig, Stourbridge, and other fireclays.

Estimation of Firing Temperature of Refractory Products.—J. W. Mellor (*Refractory Materials Section of the Ceramic Society, Transactions*, 1916–17, vol. 16, pp. 71–72), from various considerations of the question, concludes that the firing temperature of clay and silica products cannot be estimated from the microscopic appearance of the finished product.

Temperature Measurements in Preparation of Fireclay.—J. W. Cobb (*Refractory Materials Section of the Ceramic Society, Transactions*, 1916–17, vol. 16, pp. 118–120) discusses temperature measurements in clay-work practice. A number of appliances for measuring the temperatures during heating operations were exhibited and their action was explained. It was shown that the effects on the material can be produced as well by a lower temperature maintained for a longer period as by a higher temperature acting for a shorter period. The Thread recorder, the Féry radiation pyrometer, optical pyrometers, the Seger cone, Holdcroft bars, Buller's rings, and Wedgwood's pyrometer are all referred to.

Preparation of Refractory Material.—A. V. Bleininger (*Journal of the Franklin Institute*, February 1917, vol. 183, pp. 127–167) reviews

the development of the ceramic industries in the United States, and the application of scientific methods to the investigation of clays. The effect of electrolytes on clays in the plastic state is referred to, and has led to some useful discoveries, such as the prevention of drying cracks by the use of small amounts of sodium chloride or larger percentages of hydrated lime. The burning of clay and fusion phenomena are discussed, and a list is given of the clays of industrial importance occurring in the United States. The properties of siliceous fireclays, quartzite, aluminous refractories, and magnesia refractories are considered, and some notes on their treatment and preparation are given. Several types of kilns for firing are described and illustrated.

Tests of Refractories.—A. V. Bleininger (*Proceedings of the Engineers' Society of Western Pennsylvania*, 1916, vol. 32, pp. 612–644) has studied the behaviour under various conditions of clay, silica, magnesite, aluminous, carbon, and other refractories. In particular clay refractories have been investigated with respect to porosity.

With increasing temperature the viscosity of refractories decreases, and this softening is the greater the larger the amount of fluxes present. It has been suggested, therefore, that the deformation at certain temperatures and under given load be used as a criterion of the refractoriness of firebricks. From the data recently obtained by the Bureau of Standards (Technologic Paper, No. 7), it follows that the softening of the bricks becomes clearly manifest at 1350° C., which seems a suitable temperature for this test. The load to be applied should not be greater than 40 lb. per square inch, and not less than 25 lb. The relation between the deformation temperature T and the load W in lb. per square inch is expressed by Mellor's equation: $T = Ce^{KW}$, where C = deformation temperature of specimen without load; K = a constant the numerical value of which depends upon the particular clay, and e = exponential constant.

It was found that the more siliceous the clay the less the difference between the deformation temperatures with and without load. On the other hand, the more the composition of the material approaches that of the pure clay substances the greater is the difference between the deformation temperatures with and without load. It is possible, however, to produce high-clay firebrick showing excellent resistance to load conditions by using a mixture containing as high a percentage as possible of calcined No. 1 fireclay and a very refractory bond clay. Such bricks have been found to possess an exceedingly small contraction with a load of 50 lb. per square inch and at temperatures of 1350° to 1400° C.

Silica and the Manufacture of Silica Bricks.—F. Bondolfi (*Metallurgia Italiana*, January 1917, vol. 9, pp. 4–54) publishes an important memoir on the manufacture of Dinas silica bricks and on the character, composition, properties, and preparation of the raw material used. The

analyses are given of sixty-three specimens of quartzite from various localities in Germany suitable for the manufacture of silica bricks of first-class quality ("Stella" bricks, as made by the Willisch Works at Homburg). The composition of another group of quartzites for bricks of a lower grade is also shown, with notes on the geological formations in which the mineral occurs. The system SiO_2 is discussed, and the specific weight, specific volume, range of stability, range of existence, and crystalline forms of the modifications of silica at different temperatures are shown, with diagrams showing changes of volume on burning at different temperatures. The methods of manufacture in England, Russia, France, the United States, and Germany are next dealt with, with notes on the raw material raised in each country. Finally some excellent micrographs are shown of specimens of quartzite of German, Italian, and Russian origin with their analyses and results of pyrometric tests. The work is largely a review of the researches of previous investigators.

J. S. McDowell (*Bulletin of the American Institute of Mining Engineers*, 1916, No. 119, pp. 1999–2055) deals at some length with the silica refractories. The crystal types of importance from the refractory point of view are quartz, tridymite, and cristobalite, each of which possesses α and β phases, and each of which is, moreover, convertible into the other by appropriate heat treatment. The stability relations of the silica minerals are shown in a diagram, as well as the melting points and thermal expansion. The solubilities of the various modifications and their behaviour under different methods of preparation and treatment, are discussed. In the manufacture of high-grade American silica brick the raw material used is a true quartzite, the deposits from which supplies are obtained being, in order of importance, the so-called Medina or Tuscarora sandstone of Huntingdon and Blair Counties, Pennsylvania, the Barabos quartzite of Devil's Lake, Wisconsin, and the deposits of Eastern Alabama and Colorado. The silica content of the Medina quartzite is as high as 97·80. For the manufacture of refractories the most important properties of a quartzite are mechanical strength, melting point, and behaviour on burning. If the silica is below 96 per cent. the fusion point is lowered; with 99 per cent. of silica there is insufficient alumina and ferric oxide to form a proper bond. The amount of alkalies should not exceed 0·5 per cent. The various processes employed in the manufacture of silica brick are described, and photomicrographs are given showing the constitution and structure of suitable materials. Tables are also given showing the screen analyses, temperature behaviours, physical tests, density, porosity, and cross breaking and crushing tests of silica bricks, and a section is devoted to the microscopic study of such bricks. The mode of carrying out spalling tests is described, and a bibliography of the recent literature on the whole subject appended.

F. J. Katz (*U.S. Geological Survey, Mineral Resources*, 1915, Part II. 8, pp. 55–60) reports on the production in 1915 of the various

forms of silica in the United States. The sales of quartz pegmatite and quartzite amounted to 112,575 short tons. Crude quartz for metallurgical purposes was valued at 50 to 85 cents per ton. The material commercially called tripoli in the United States is a residue from siliceous limestones which have been leached of their carbonate content. The material is nearly pure silica of very fine grain, and is principally used as an abrasive; the production of diatomaceous earth or kieselguhr, largely used for the same purpose, is also given.

Magnesite.—F. R. Feldtmann (*Report of Department of Mines, Western Australia*, for 1915, pp. 131–133) reports on the magnesite deposit recently opened at Bulong in North East Coolgardie goldfield, and 19½ miles east of Kalgoorlie. The main area of the deposit is over two miles in length with an average width of 18 chains. The magnesite occurs as short irregular veins in the serpentine rock. The work of opening up the area has not sufficiently progressed to enable any estimate to be formed as to the quantity of mineral present, but there is a large quantity of magnesite carrying over 90 per cent. of magnesium carbonate. In 1915, 688 tons of magnesite were shipped from the mines.

Magnesite Bricks.—According to A. Stansfield of the Canada Department of Mines (*Iron and Coal Trades Review*, January 1917, vol. 94, p. 31) electric steel furnaces in the United States, Canada, and elsewhere have been very seriously handicapped by the extreme difficulty of obtaining magnesite bricks. The Canadian magnesite obtained from the Calumet district is not ideal for the production of firebricks, as it does not sinter on burning and its lime contents are rather high, being frequently in the neighbourhood of 10 per cent. Experiments have been made in which iron ore was added so as to cause it to sinter, thus producing a dense product suitable for lining furnaces or for making bricks. H. J. Ross, of the North American Magnesite Company, states that their magnesite has been used in large quantities for lining open-hearth furnaces, the burnt magnesite being mixed with basic slag as in the ordinary practice, and this has the effect of causing it to sinter in the furnace. They have even been able to dispense with magnesite brick in these furnaces, as is indicated in the following instructions supplied by him: The crude magnesite is partially burned —say four or five hours in an ordinary heating furnace, but, if more convenient, a cupola, or rotary kiln, or a continuous heating furnace may be used. Then draw and mix it thoroughly on the floor with 10 to 15 per cent. of good basic slag. Put it in the bottom of an open-hearth furnace and treat it like Austrian magnesite. This material has proved equal to any material ever used for rolling or tilting furnaces. One advantage of it is that the bottoms can be set in one-half the time required for the Austrian magnesite. The material has been in use in one plant for the last eight months, where it could be compared with

the Austrian magnesite, and with the disadvantage of having no magnesite brick. In this case the hearth was lined entirely up to the slag line with clay brick, and after this eight months' test the results were found to be fully equal to the Austrian magnesite. Exceptionally fine results are obtained by using it for closing tap holes.

H. B. Cronshaw (*Refractory Materials Section of the Ceramic Society, Transactions*, 1916–17, vol. 16, pp. 101–105) writes an account of a curious mineral occurring in a magnesia brick.

Synthetical Reproduction of Magnesioferrite Ore.—A process for reproducing magnesioferrite ore synthetically has been patented by C. B. Stowe (*Iron Trade Review*, 1917, vol. 60, pp. 203–204; *Mechanical Engineer*, 1917, vol. 39, p. 124) and has proved commercially successful. The basis of this artificial refractory is natural magnesite which is practically free from iron. To this is added iron in the form of hæmatite or other ore in the form of rolling-mill scale. Enough water is added to the mixture to give it the consistency of mud. The mud is moulded and baked until it is hard enough to withstand the pressure of stacking, when the moulds are placed in a kiln and baked, driving off the carbonic acid gas and water and causing the iron to unite with the magnesia. The temperature employed in the kiln ranges between the melting points of No. 11 and No. 19 Seger pyrometric cones. This heat is maintained from thirty-six to forty-eight hours. The process, however, is not completed by one burning, but requires at least two burnings and three grindings before a satisfactory brick is produced. The material is broken up and ground before each burning. When crushed, it is suitable for use as grain bulk for linings after the first baking. One of the greatest advantages of this process is that the percentage of iron may be regulated to suit any particular purpose for which the furnace is to be used. Such regulation was almost impossible with the natural ore. The appearance and analysis of the manufactured magnesioferrite resembles very closely that of the natural Austrian ore.

Firebricks, Manufacture of.—R. H. H. Pierce (*Steel and Iron*, January 1916, vol. 50, pp. 20–23) discusses the raw materials from which bauxite bricks, silica bricks, and magnesite bricks are prepared, and the factors to be taken into account in manufacturing such bricks.

W. Gray (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 209–216) describes and discusses the relative advantages and properties of magnesia, chrome, bauxite, fireclay, and silica brick, and the raw material and mode of manufacture employed in the manufacture of the latter. Two kinds of silica refractories are recognised in America: brick high in silica and brick low in silica. The chemical and physical properties of both types are dealt with in detail, including expansion, porosity, density, permeability, conductivity, and strength, as measured by the load test. The special uses of silica

brick for checker work, boiler furnaces, coke-ovens, limekilns, cupolas, and gas-retorts are also described.

C. S. Kinnison (*Blast-Furnace and Steel Plant*, May 1916, p. 232, 4 pp.) describes modern methods for the manufacture of fireclay refractories for service in the steel industry.

Gas-Fired Kilns for Burning Bricks.—A description is given of the Dunnachie continuous regenerative gas-fired kiln for burning refractory bricks (*Iron and Coal Trades Review*, January 1917, vol. 94, p. 10). The kiln consists of ten chambers in two parallel rows of five each, the whole being under roof and the space between the rows being used for a drying stove, heated by the gas passing from the producer. The gas and air come in sideways from parallel checkered flues running the whole length of the kiln chamber (17 feet long by 10 feet 6 inches by 10 feet 6 inches) and meet in the burner, which is another flue of the same length lying between them. This burner is one of the chief features of the kiln. In it all the gas and all the hot air meet, spread out, and are correctly proportioned at every point. Where the draft is made to enter the kiln chamber from corner ports, or flues otherwise situated, the same uniformity cannot be attained, and as a consequence bars of well-burned and under-burned bricks are found side by side.

The producer, which is placed at one end of the kiln, is of the Imperial type. It is fitted in the centre with a treble-stepped cone which is made to deliver the air and steam round the circumference of the several cones. The producer is 9 feet in diameter, and is capable of gasifying 10 cwt. of fuel per hour; at Glenboig, however, it is worked considerably below its duty, the consumption being from 6 to 7 tons in the twenty-four hours. The gas is taken off in a main 3 feet in diameter, lined with 3 inches of brickwork, and is taken to the kiln chamber at a temperature of 600° to 800° F.

Selection of Firebrick.—Some factors governing the selection of firebrick are noted (*Blast-Furnace and Steel Plant*, March 1916, pp. 127–128). There is no universal type of firebrick suitable for all the needs of blast-furnaces and steel furnaces, and some recommendations as to tests of bricks are made.

Kieselguhr Products in Metallurgy.—The growing use of the kieselguhr products "Celite" and "Silocel" is noted (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 54–55). They are employed in hot-blast stoves working at unusually high temperatures, in crucible furnaces, where their insulating properties are valuable, in regenerators, and as by-product coke-oven insulators.

Use of Celite for Insulation of Blast-Furnace Stoves.—P. O. Boeck (*Paper read before the Chicago Section of the American Society of Mechanical Engineers*, January 14, 1916; *Blast-Furnace and Steel Plant*, February 1916, vol. 50, pp. 61–66) has investigated the heat

losses in hot blast-furnace stove mains and stacks and the best methods of insulation for the prevention of such losses. The rate of heat flow through various bodies is first referred to, and a diagram is reproduced from a report by B. Dudley (*Transactions of the American Electrochemical Society*, 1915) showing the results of tests made to ascertain the thermal conductivity of firebrick at various temperatures.

It is rare that a good refractory material is an insulator, and usually it is necessary to back up the refractory with some material having a much lower heat-conducting capacity. Insulating material should be of a composition that will not attack either the refractory material or the metal shell of the container even in the presence of moisture. It should not have high expansion and should be sufficiently elastic to take up strains, produced by temperature changes between the lining and the shell of stoves or furnaces. Magnesia and asbestos are ruled out of consideration here on account of decomposition and shrinkage.

The mineral known as celite, on account of its extremely cellular nature, is a product of a highly siliceous composition and of very light weight, which occurs on the Pacific coast, in an exceptionally pure state. It is composed of numerous hollow cells, and weighs in its natural rock-form, air dried, from 25 to 30 lb. per cubic foot. When this material is ground properly, so as not to destroy its cell structure, a powder is produced, which weighs only 8 lb. to the cubic foot and has a thermal insulating power about equal to that of cork, or from nine to ten times the insulating power of ordinary firebrick. Being almost pure silica, its melting point is high, 1610° C., as reported by the Bureau of Standards, and it can be subjected to high temperatures without fear of alteration.

Celite is adaptable to any form of thermal insulation. In general, there are four forms of construction for high temperature insulation. The usual method is using the brick interlaid between a course of firebrick and red brick for the prevention of heat leakage through walls. This form of construction is largely used in boiler settings, reverberatory furnace walls and roofs, &c.

One of the methods of construction of an insulating wall is that in which an otherwise hollow space is filled with insulating powder. From 2 to 4 inches are usually sufficient. The powder is packed slightly to a density of approximately 12 lb. to the cubic foot, at which it attains its maximum insulating value and is not subject to settling or contraction due to either vibration or heat. Where this form of construction has been in severe service in high temperature furnaces for a period of years, no contraction or settling has taken place.

Casting of Clay Wares.—T. G. MacDougal (*Report to the Department of the Interior, United States; Engineering Review*, October 1916, vol. 30, No. 4, pp. 113–117) describes general practice in the casting of clay wares. The causes are indicated of the variation and uncertainty in the results obtained in different works.

Yorkshire Fireclays.—W. G. Fearnsides (*Paper read before the Midland Institute of Mining Engineers*, December 1916; *Iron and Coal Trades Review*, December 1916, vol. 93, pp. 726–727) discusses the properties of refractory materials in the South Yorkshire coalfield. The most refractory of Yorkshire fireclays, the Black Bed of Stannington, has its outcop in the immediate neighbourhood of the places where the tilt hammers for power forging of steel were set up. This Stannington Black Bed, better known as the Pot Clay, is the lowest bed of the Yorkshire Coal Measures, and rests directly upon the Millstone Grit. It is a clay comparatively easy to manufacture, and for more than a century has kept its reputation as a suitable material for lining furnaces wherein intense and long-continued heat is required. For almost as long a period it has been used as an essential constituent for the making of crucibles or "pots" in which, by the famous Huntsman's process, the best-class steels of Sheffield are still prepared for casting. The blending of clays for pot-making is a process generally maintained as a family secret, but by nearly all the makers some 25 per cent. of pot clay from the Stannington Black Bed is used. A bed of fireclay, the equivalent of the pot clay, underlies the Coal Measures of Yorkshire from the north-east corner of the coalfield near Leeds, westward by Halifax, and southward past Sheffield and west of Chesterfield, almost to Nottingham in the south. Throughout the coalfield the lowest seam of coal which belonged to the Coal Measures has as its underclay this celebrated pot clay, which, when sufficiently weathered, is highly refractory.

In the seat-earth of the Whinmoor Coal there is a refractory material in which the siliceous part is a fair ganister, but which carries small ironstone nodules which spoil it, and has also rather too impure a clay admixture for it to be made up into high-class refractory bricks. There are certain bands associated with the Parkgate Coal which serve as holing dirt in the middle of the Parkgate seam, which make good second-grade firebricks; there are also certain bands associated with the Flockton seam which are fairly refractory, and these ought to be investigated over a wider area. There are certain second-rate fireclays associated with the Barnsley Coal which are useful for furnace building in those parts of the construction where the temperature is not allowed to pass about 1100° C. But for high-class refractory materials, such as are needed in the iron and steel furnaces of Sheffield, the main supply is certainly to be found at the bottom of the Lower Coal Measures, and possibly also among the upper beds of the Millstone Grit.

The clays of Northern Yorkshire form the subject of a paper by P. F. Kendall and A. Gilligan (*Refractory Materials Section of the Ceramic Society*, March 13, 1917).

Refractory Sands in England.—W. G. Fearnsides and P. G. H. Boswell, in a paper read at a meeting of the British Association (*Foundry*

Trade Journal, October 1916, vol. 18, p. 531), describe the occurrence of refractory sands and associated materials in a series of large cavities in the limestone rocks of Derbyshire and Staffordshire. They found that these hollows contained detrital remains from rocks which once covered the district, but which had since entirely disappeared by denudation. As a matter of fact, these materials had been accidentally preserved, and had proved of the greatest possible economic value, inasmuch as they were far better than the material previously obtained from Germany and the Continent for lining retorts, and could be worked at the surface at a minimum cost.

Fireclay in Canada.—B. Rose (*Canada, Department of Mines*, Memoir 89, 1916, No. 75 Geological Series, pp. 69–86) has examined the occurrence and distribution of clay, clay-shale, and sands suitable for the manufacture of clay products, in the Wood Mountain and Willowbunch areas, in Saskatchewan. Most of the workable clays are found in the Fort Union formation. They are closely associated with lignite and in places the two can be mined together. Many of the clays are semi-refractory and some can be classed as fireclays. Results of tests of a number of samples are given.

Russian Fireclays.—P. Zemiatcensky (*Imperial Academy of Sciences*, Petrograd, October 1 and 19, 1916) describes experiments made with the object of determining the absorptive capacity of Russian clays. A further report describes the deposits of fire-proof clay in the neighbourhood of Latna on the Kieff-Voronez Railway, at Lepecka (Tambov Government), and at Cirikov (Voronez Government).

Bauxite.—W. C. Phalen (*U.S. Geological Survey, Mineral Resources*, 1915, Part I. 7, pp. 159–174; *Foundry Trade Journal*, December 1916, vol. 18, p. 661) deals with the use of bauxite bricks for furnace linings. The purer the material used, the more refractory is the resulting brick; moreover, the addition of bauxite to refractory clays, not only increases their content of alumina but also their refractoriness. The two kinds of bricks in common use, made of hydrous oxide of aluminium, contain 56 and 77 per cent. alumina respectively. The lower percentage bricks are used as fireclay bricks, but will withstand higher heat. The bricks containing the higher percentage have been used as a substitute for magnesia (commonly called magnesite) bricks for open-hearth and similar work. An instance is cited where bauxite bricks were used in the port end of a furnace, forming a bulk-head for that particular open-hearth furnace for 365 heats, at the end of which time a new roof was installed. The opposite port, in which magnesia bricks were used, was found in a worse condition.

The production of bauxite and aluminium in the United States in 1915 is reported, and the figures of the world's production are also

given. The bauxite industry is reviewed and a new occurrence in Georgia is reported, analyses of samples showing 51 to 54 per cent. of alumina with iron oxide and silica. Deposits of bauxite have also been found in British and Dutch Guiana, and mining operations have begun in the latter colony. For the present the leases in British Guiana have been held up by the British Government, to whom all applications have to be referred for approval.

Magnesite in Italy.—In a report (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 490) recently issued by the Government Inspector in response to a request on behalf of the Association of Italian Metallurgists to have the value of magnesite deposits in the country investigated, it is stated that the deposit now being worked by the Livorno Magnesite Company in the quarry at Castiglioncello contains certainly more than a million tons of the mineral, which can be easily quarried at the rate of 80 tons per day. The output between May and October last year, however, did not exceed 1760 tons. The analyses of samples taken at five different visits are given in the following table :

Analyses of Magnesite Samples.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Moisture and loss in fire	49·20	49·55	49·97	49·30	49·68
Silica	3·40	2·39	2·50	3·35	2·06
Oxide of iron	1·60	2·30	1·90	2·20	2·20
Lime	3·02	3·34	2·90	2·68	2·88
Magnesia	42·45	42·89	42·67	42·16	43·07
Total	99·67	100·47	99·84	99·69	99·89
Carbonate of magnesia	88·72	89·74	89·20	88·11	90·03

Magnesite in Canada.—H. Frechette (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, pp. 139–147) reports the occurrence of magnesite and hydro-magnesite in more or less abundance in several localities in Canada, and gives analyses of several samples from British Columbia. The magnesia ranges from 35·23 per cent. as a minimum to 43·70 maximum. The most important deposits are found in Quebec. The production of magnesite has greatly increased in consequence of the war, as shown by the following figures furnished by the Statistical Division of the Mines Branch, Ottawa :

	Tons.
1912	1,714
1913	515
1914	358
1915	14,779 (including some calcined).

Magnesite in the United States.—Statistics are given (*Iron Trade Review*, vol. 60, 1917, pp. 471–472) of the magnesite produced in the United States in 1915, which amounted to 30,499 short tons as compared with 11,293 short tons in 1914. The domestic material continues to be derived from California exclusively from sixteen mines in the

counties of Alameda, Fresno, Kern, Napa, Santa Clara, Sonoma, and Tulare. All the magnesite from the larger properties is calcined in local furnaces before any attempt is made to market it. The value assigned to the domestic product in 1915 is based on a price of $22 to $25 a ton of ordinary calcined magnesite, not ground, in sacks at San Francisco, which is assumed to be approximately equivalent to $9 a ton for the raw or crude magnesite at the same point. The ground magnesite brings a somewhat higher price in California markets, but the imported magnesite sells at a price above that of the domestic product, the reason being that the imported material is more finely ground, is put up in better packages, and may be purchased in smaller lots on longer credit than the domestic. The total imports fell materially in 1915, as compared with 1914, owing to conditions in Europe. On the last months of 1914 and in the first two months of 1915 the shortage in the United States caused somewhat unusual shipments. Since March 1915 no magnesite has been received in the country from Austria.

Graphite.—E. S. Bastin (*U.S. Geological Survey, Mineral Resources*, 1915, Part II. 11, pp. 81–93) reports on the production of graphite and imports into the United States. The developments up to 1915 in graphite-mining in the different States are recorded and the position of the graphite industry is reviewed.

The graphite deposits of the Buckingham district in the province of Quebec are described by M. E. Wilson (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, pp. 362–368). A microsection showing the relationship of the graphite to pyrite in disseminated graphite ore is given. Some notes deal with the origin of the graphite and the graphite industry.

A valuable vein of graphite is reported by the *Board of Trade Journal* to have been discovered at Anisok in Greenland and is now being worked. The last vessel arriving at Copenhagen from Greenland brought 800 tons of graphite. A factory for the utilisation of graphite has been erected in Denmark (*Journal of Industrial and Engineering Chemistry*, November 1916, vol. 8, p. 1072).

Zirconium.—J. W. Richards (*Paper read before the American Chemical Society*, September 1916) discusses the use of zirconium oxide as a refractory, either as brick or as a substitute for magnesite.

Intumescent Kaolinite.—W. T. Schaller and R. K. Bailey (*Journal of the Washington Academy of Sciences*, 1916, vol. 6, pp. 67–68) describe a sample of kaolinite from eastern Oklahoma. The mineral formed small compact lumps with a glistening or fine satiny appearance. Under the microscope the material appeared pure, homogeneous, and well crystallised in minute hexagonal plates and crystals. In testing the fusibility it was found to intumesce strongly, and only in

this respect differed from kaolinite. The chemical analysis is shown under (1) below, and for comparison the theoretical composition of kaolinite is given under (2):

	1.	2.
SiO_2	46·55	46·50
Al_2O_3	38·90	39·56
H_2O	14·04	13·94
	99·49	100·00

The figures show the chemical identity of the Oklahoma mineral with kaolinite.

China Clay.—J. M. Coon (*Paper read before the Royal Cornwall Polytechnic Society; Mining Magazine*, April 1917, vol. 16, pp. 215–217) deals with the development of mechanical appliances on china-clay works and with the mining and preparation of china clay. The operations connected with the winning of china clay may be summarised under the headings: (1) Breaking the clay, rock or ground; (2) Separation of the clay; (3) Pumping of clay-bearing water and draining the pit, haulage, &c.; (4) Disposal of waste; (5) Drying; (6) Transit to port; and these are fully described.

Furnace for Testing Refractories.—E. Griffiths and E. A. Griffiths (*Paper read before the Faraday Society*, December 18, 1916) describe a carbon tube furnace for testing softening points and compressive strengths of refractories.

Petrographic Microscope.—F. E. Wright (*Journal of the Washington Academy of Sciences*, 1916, vol. 6, pp. 465–471) describes improvements in the petrographic microscope, the new accessories being a sliding objective changer, a lens system for removal of astigmatism caused by analyser, a prism for observation of interference figures, and a device for use in the accurate measurement of extinction angles.

FUEL.

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I.—*CALORIFIC VALUE.*

Wedge Optical Pyrometer.—An illustrated description is given (*Iron and Coal Trades Review*, December 1916, vol. 93, p. 756) of the Wedge optical pyrometer. The instrument consists of a square brass tube furnished with a small telescope, so arranged that the objective of the telescope focusses the magnified image of the heated body on a movable prism placed inside the tube, and actuated by a rack and pinion. There is a suitable shield provided to prevent exterior light reaching the eye. The prism is made of specially prepared dark glass, so arranged that it cuts off at various temperatures the light emitted by a heated body. The instrument was invented by Messrs. Cochrane and Company, of Middlesbrough, for use in their own works, and it is now manufactured for sale by the Optical Pyrometer Syndicate (London).

Fusion Tests of Ash.—F. C. Hubley (*Power*, 1916, vol. 44, pp. 591–592) has found that the use of varying amounts of dextrine as a binder for the test-sample appears to have a considerable effect on the nature of the fusion and the final melting point. A number of ash samples representing coals from different localities were mixed with various amounts of dextrine, and fusion curves were taken and compared with the binder-free ash fusion. The results were so variable as to show that the use of binder for cones in fusion work is prohibitive. Comparatively small amounts of carbon appeared to change the position of the melting point, so that some mention should be made in specifications of the maximum amount of carbon in the sample after incineration.

Sampling Coal and Specifications of Coal.—G. S. Pope (*U.S. Bureau of Mines*, Bulletin 116, 1916, pp. 1–61) reports on methods of sampling

delivered coal and specifications for the purchase of coal by the United States Government. The report contains directions for sampling, a description of the appliances used, and specifications and proposals for bituminous and anthracite coal.

Use of Pulverised Coal as Fuel.—J. W. Fuller (*Paper read before the American Iron and Steel Institute*, October 1916; *Blast-Furnace and Steel Plant*, November 1916, pp. 519–524) gives an account of the practice in the use of powdered coal as fuel for open-hearth furnaces. Very fine pulverisation is necessary to ensure complete combustion immediately on entering the furnace, so that there shall be as little free oxygen as possible in the gases and that the sulphur is immediately burnt to sulphur dioxide. The preparation of the coal and the feeding arrangements are described.

J. Harrington (*Journal of the American Society of Mechanical Engineers*, 1916, vol. 38, pp. 796–799) discusses the methods in use in the United States for the pulverising of coal and the handling and firing of powdered coal. The advantages of such fuel when employed in certain types of furnace are considered and some figures showing the cost of pulverising are given.

H. G. Barnhurst (*Journal of the American Society of Mechanical Engineers*, 1916, vol. 38, pp. 799–801) gives a short description of an installation of ten O'Brien boilers burning pulverised low-grade coal including lignite. Data concerning the efficiency are given.

J. E. Muhlfeld (*Journal of the American Society of Mechanical Engineers*, 1916, vol. 38, pp. 983–990; *Iron and Coal Trades Review*, October 1916, vol. 93, p. 489) gives particulars regarding the use of powdered fuel on locomotives. According to him a saving of from 15 to 25 per cent. in coal of equivalent heat value fired can be effected by using coal in a powdered state mixed with steam and blown into the firebox by special apparatus, as compared with the usual hand-firing with lumps thrown on the grate.

An equipment for firing stationary boilers with pulverised coal on the Kansas and Texas railroad is illustrated and described (*Railway Age Gazette*, 1916, vol. 61, pp. 549–551; *Journal of the American Society of Mechanical Engineers*, 1916, vol. 38, p. 932). Various tests with different classes of coal have proved entirely successful, and particulars of costs and of the efficiency of the system are given.

Economical Utilisation of Coal.—W. A. Bone (*Report to the British Association, Newcastle Meeting*, 1916) presents a preliminary report on the coal reserves of the world and on the inquiry in progress concerning the directions in which economy in the use of coal can be secured.

Other papers by the same author (*Proceedings of the South Wales Institute of Engineers*, 1917, vol. 32, pp. 373–395) deal with fuel economy and the utilisation of coal.

Professor Brame (*Series of Lectures delivered before the Royal Society*

of Arts, London; Journal of Industrial and Engineering Chemistry, vol. 9, 1917, p. 319) considers the economic utilisation of coal, referring to the composition of coal, and of coal as a source of heat and power; he also deals with the by-products of coal in general. Some of the problems connected with low temperature carbonisation might be successfully attacked by applying the methods which have been found so useful in the case of alloys—the use of solvents in conjunction with the microstructure. In dealing with the prospects for the more economical use of coal, reference is made to the use of powdered coal and to the advantage of briquetting coke-dust.

C. E. Strohmeyer (*Mechanical Engineer*, 1916, vol. 38, pp. 400–402) reviews the ordinary conditions under which coal is consumed for industrial purposes, and points out the various directions in which economy of coal in power production could be secured.

F. F. Mairet (*Paper read before the Midland Institute of Mining, Civil, and Mechanical Engineers*, July 18, 1916; *Iron and Coal Trades Review*, 1916, vol. 93, pp. 70–71) considers the economical production and utilisation of power at collieries. Arising out of his paper a general discussion on fuel economy at collieries took place (*Iron and Coal Trades Review*, 1916, vol. 93, pp. 454–455).

Properties of Solid Fuel.—S. G. Martlew (*Paper read before the Association of Engineers-in-Charge*, December 13, 1916; *Mechanical Engineer*, vol. 39, 1917, pp. 17–19) compares the properties of various solid fuels, particularly anthracite, semi-anthracite, semi-bituminous and bituminous coal, lignite, briquettes, and pulverised coal. He also deals with coal-handling and storage, and the by-products of coal-gas manufacture.

Surface Combustion.—A heat-treating plant employing surface combustion and comprising three units of one hardening and one tempering furnace, or six furnaces in all, is described and illustrated (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 363–364). The plant is situated at the works of the Eddystone Ammunition Corporation, Eddystone, Pennsylvania, the gas used being town gas. Each unit consumes about 3300 cubic feet per hour, and the cost has been found less than that of similar furnaces oil-fired.

H. L. Read (*Mechanical Engineer*, vol. 39, 1917, pp. 243–244) furnishes the results of recent work in surface combustion.

Gas-Firing Devices for Boilers.—Pradel (*Zeitschrift für Dampfkessel und Maschinenbetrieb*, 1916, vol. 39, p. 315, serial article; *Journal of the American Society of Mechanical Engineers*, 1917, vol. 39, pp. 91–92) gives an illustrated description of burners and piping for gas-fired boilers. The Moll burner with pilot and main fires is shown, also some types of automatic cut off safety-valves.

Smoke Abatement.—W. F. M. Goss (*Proceedings of the Engineers Society of Western Pennsylvania*, 1916, vol. 21, pp. 310–329) considers the general effect of the electrification of railway termini and of the application of electricity to operations within their area on reducing the smoke nuisance. The question is mainly one of cost of the necessary installation and of the proportion which the quantity of coal consumed by locomotives, &c., bears to the total quantity contained in the whole district.

O. Monnett (*Proceedings of the Engineers' Society of Western Pennsylvania*, 1916, vol. 32, pp. 772–781) considers the engineering phases of smoke abatement and the arrangements to be recommended for securing smokeless combustion.

Chimney Construction.—T. H. Ward (*Minutes of Proceedings of the Institution of Civil Engineers*, 1915–16, vol. 202, pp. 350–356) describes a method of repairing factory chimneys which he has successfully used at the East Indian Railway Collieries. The chimney was octagonal and a scaffold was devised which automatically adjusted itself to the varying dimensions of the cross-section when going up or coming down. The problem also involved the fixing of points of support on the chimney itself at an accessible distance above one another from which the scaffold could be suspended and raised or lowered.

Application of Volcanic Heat for Power Production in Italy.—Luiggi (*Engineering*, November 1916, vol. 102, pp. 487–488) states that coal has reached an unprecedented price in Italy. A scheme has been put in operation for heating boilers by means of the natural jets of steam which occur at Larderello in Tuscany. The hot jets are used to raise steam in boilers which is employed in condensing engines, and the power is transmitted to various cities in Northern Italy. The utilisation of volcanic heat near Naples is also in contemplation.

II.—*COAL.*

Geology of Coal.—E. H. Staples (*Transactions of the Manchester Geological and Mining Society*, 1916–17, vol. 35, pp. 17–27) has studied the effects of the master folds upon the structure of the Bristol and Somerset coalfields.

Weathering of Gas Coals.—A. H. White (*Journal of Gas Lighting*, 1916, vol. 136, pp. 541–544; *Journal of the Society of Chemical Industry*, vol. 36, 1917, p. 24) describes and gives results of tests on the weathering of gas coals conducted at the gas experimental station maintained by the Michigan Gas Association and the Chemical Engineering Department of the University of Michigan. The tests were made on Pittsburgh and Fairmont gas coals stored for varying periods, and the results

showed that each of these types could be exposed to the weather for five years (provided they do not heat in storage) and at the end of that period be entirely satisfactory gas coals.

Specific Gravity of Coal.—M. L. Nebel (*University of Illinois*, Bulletin No. 89, 1916, vol. 13, pp. 1–49) has carried out an investigation to determine the effect of moisture on the specific gravity of coal and the methods of determining the specific gravity. The practical uses of the specific gravity of coal are stated and a number of conclusions are drawn. The coals experimented with and the results obtained all relate to Illinois coal.

Oxidation of Coal.—G. Charpy and M. Godchot (*Comptes Rendus*, 1916, vol. 163, pp. 745–747) have carried out experiments on the oxidation of coal. Measurements were made of the changes undergone by samples of coal on exposure to the air at temperatures of 100° to 150° C. for given intervals. A diminution of weight was first observed, equal to the loss of water through evaporation; a loss which at 100° C. continues for about three hours. A gradual increase in weight then takes place, reaching a maximum value of 3 to 5 per cent. after an interval of two to three months. This change is accelerated by increase of temperature, but at 150° C. an evolution of carbon dioxide occurs, resulting in loss of weight. This slow oxidation of coal causes a loss in its calorific value which in some cases was found to amount to 13 per cent. The amount of ash and volatile matter were found to be unaffected by prolonged oxidation. The results show that since this oxidation of coal can proceed under ordinary atmospheric conditions, the calorific power of different samples cannot be deduced from the content of ash and volatile matter but that a direct calorific measurement is necessary.

T. J. Drakeley (*Transactions of the Chemical Society*, 1916, vol. 109, pp. 723–733; *Journal of the Society of Chemical Industry*, 1916, vol. 35, p. 1001) describes experiments showing that iron pyrites has a minor effect upon the oxidation of coals, and its presence cannot be ignored, even though non-pyritic coals may be amongst those most liable to ignition. A difficulty is experienced in drawing conclusions from the percentage of sulphur in a coal, as pyrites disseminated throughout a coal in microscopical particles will act more effectively than larger quantities of nodular pyrites. Even though samples be drawn from the same seam, it is almost impossible to make inferences from analyses, as great differences may exist in the physical conditions of occurrence. A fault, or a poor roof, may have, it is stated, a more predominating influence than the percentage of sulphur on the ignition of the coal.

Analyses of American Coals.—M. R. Campbell and F. R. Clark (*U.S. Geological Survey, Economic Geology*, Bulletin 621–P, 1916,

pp. 251–375) give tables of analyses of all coal samples collected by the U.S. Geological Survey in 1914 and the first five months of 1915. The classification comprises anthracite, semi-anthracite, semi-bituminous, bituminous, sub-bituminous, and lignite. Samples from thirteen States are recorded with full analyses.

Survey of Coalfields in England.—The *Summary of Progress of the Geological Survey of Great Britain* for 1915 contains an account of the Geological Survey for that year. It includes the mapping of the Denbighshire and Shropshire district and the completion of the survey of the country contiguous to the Warwickshire coalfield. The possibilities of the extension of the coalfield are reviewed.

Fuel Resources of the United Kingdom.—W. S. Boulton (*British Association, Newcastle Meeting*, 1916), in his Presidential Address to the Geological Section of the British Association, refers to the extension of surveys for coal and the investigation of coal-seams, the prospects of increasing the production of petroleum, and to the development of the utilisation of peat in the United Kingdom.

Coal in Scotland.—A lengthy report, entitled *The Economic Geology of the Central Coalfield of Scotland*, has been published by the Geological Survey, Scotland (*Memoirs*, 1916, pp. 1–146). The area dealt with comprises about 100 square miles, extending from Glasgow westward to beyond Longriggend. Sections of the field and maps accompany the report.

Coal in Germany.—An account is given (*Engineering*, March 1917, vol. 103, pp. 216–217, and May, p. 483) of the coal resources of the Ruhr district, and the West Rhenish, the Aachen, and the Saar districts. The coal reserves of the Ruhr district are estimated at 213,796 million tons, the West Rhenish basin contains about 7100 million tons, the Brüggen-Erkeleng district is estimated to contain 1732 million tons, and the Aachen basin about 1567 million. The Saar district is calculated to have reserves amounting to 16,548 million tons. The total annual production before the war was about 55 per cent. that of Great Britain, though Germany's coal resources, including lignite, are more than double those of the United Kingdom. Some notes on the characteristics of the German coal and of the proportion of by-products obtainable are given.

The coal resources of Silesia and Saxony are also reviewed with notes on the character of the coal obtained from these localities. The resources of Upper Silesia are estimated at 1659·87 million tons and those of Lower Silesia at 2944 million tons. The resources of Saxony are computed at 225 million tons.

State-Owned Coal-Mines in Prussia.—The Prussian Crown has completed the purchase of the Hibernia collieries in Westphalia

(*Engineering*, November 1916, vol. 102, p. 515). Since 1904 the Crown held shares to the amount of 27½ million marks, and has now become possessed of the property altogether by the acquisition of 23,520,000 marks ordinary shares and 10,000,000 marks preference shares of the Herne Trust, and 8,500,000 marks ordinary shares held by private parties. The terms of purchase have not yet transpired. The Crown mines in Westphalia previously represented about 200 million marks, and by the additional purchase the Crown heads the list as regards allotment within the Rhenish-Westphalian coal syndicate with an aggregate production of about 12 million tons annually.

Coal in Iceland.—Preliminary explorations for coal in West Iceland (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 521) were made in 1915 and were continued in 1916. These showed that the coal improves as the workings go further into the mountains. The coal first obtained was a kind of lignite; the best of it was somewhat black and heavy, but of fair quality, and doubtless suitable for domestic use. It is pointed out, however, that even if the coal proves better in quality than the samples hitherto obtained, considerable difficulties of shipment and transport will have to be surmounted.

A Swedish expert (*Iron Trade Review*, 1917, vol. 60, p. 424) who has been investigating the extent of coal deposits in Iceland has estimated the supply of this fuel to be approximately 180,000,000 tons. The coal is said to be equal to Scotch coal, and it is thought that if, on account of its large percentage of ash, it is found to be unsuited for steamship fuel, it will be used for power-station fuel.

Coal in South Manchuria.—The development of the coal-mines of the South Manchuria Railway at Fushun, Yentai, and Chatzuyao, near Wafangtien, is reviewed (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 476). The coalfield runs for about twelve miles parallel with the river Hun, and the seams dip at an average gradient of about 30° towards the river. The deposits are 80 to 175 feet in thickness, and contain at least 800 million tons of coal. At the outset the working was primitive, with a daily output of only 300 tons, which was all used up by the military. With the introduction of machinery and improvements, however, the total daily output of the seven pits now in operation has been increased to 4000 tons.

Coal in Southern Nigeria.—In the course of a survey of Southern Nigeria (*Iron Trade Review*, 1917, vol. 60, p. 424) deposits of lignite and coal were discovered on both sides of the river Niger near Asaba, and in the Udi-Okwoga region. The total area of these coal lands is estimated at about 1800 square miles. The railroads of Nigeria are at present the chief consumers of coal in the country, and development of the territory has been undertaken by the public works department.

A railway has been built to connect the mines with Port Harcourt. The Udi coal is a black bituminous compact coal of good quality. A number of analyses are given. Up to December 1915 about 7200 tons had been raised.

Coals of Canada.—A further report on the investigation of the coals of Canada has been published, prepared by J. B. Porter assisted by others (*Canada, Department of Mines, Mines Branch*, No. 338, 1915, pp. 1–194). The present report deals with the weathering of coal and forms a supplementary volume to Report No. 83 of the Mines Department.

The coal-fields of the Wood Mountain and Willowbunch areas in Saskatchewan have been reported on by B. Rose (*Canada, Department of Mines*, Memoir 89, No. 75 Series, 1916, pp. 1–69). The area is abundantly supplied with lignite coal of good quality, analyses of which are given.

Coal in Newfoundland.—J. W. McGrath (*Canadian Mining Journal*, 1916, vol. 37, pp. 439–441) refers to the coal deposits of Newfoundland. There are three distinct coal-fields. In the one situated in the valley of the Codroy Rivers only a small section of the Coal Measures is to be found. Six seams of coal of excellent quality are known here, one of them 9½ feet thick at its outcrop; another, as far as examined, showed an average thickness of 7½ feet. The other four are much smaller.

Coal in the United States.—C. T. Lupton (*U.S. Geological Survey*, Bulletin 628, 1916, pp. 1–86) reports on the geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah. An index map of the district is given.

D. E. Winchester and others (*U.S. Geological Survey*, Bulletin 627, 1916, pp. 1–169) report on the lignite field of north-western South Dakota.

Coal in Western Australia.—H. P. Woodward (*Geological Survey of Western Australia*, 1915, No. 64, pp. 7–12) describes the coal resources of Western Australia.

Coal in North Borneo.—W. Hopwood (*Paper read before the National Association of Colliery Managers; Iron and Coal Trades Review*, November 1916, vol. 93, pp. 574–575, 674–675) gives an account of coal-mining in North Borneo. Although coal is found in abundance all over Borneo, until recently its development has been confined to the west. The Island of Labuan is the only coal-producing colony owned by Great Britain in the whole of the China Seas (north of Australia). The Labuan deposit contains an excellent steam fuel, very

much superior to the lignites of the Western States of America. It does not deteriorate or disintegrate when exposed to the sun and atmosphere. As the result of tests the British Admiralty have pronounced it the best produced in the East.

Peat.—Progress in the utilisation of peat is reviewed, and some particulars of the practice of cutting and preparing peat are given (*Bulletin of the Imperial Institute*, 1916, vol. 14, No. 1, pp. 81–88).

The value of peat powder as fuel for steam-raising purposes on railways is discussed (*Engineering*, October 20, 1916, vol. 102, p. 387). A large number of experiments were made with locomotives on the Hallsberg-Mjolby section of the Swedish State Railways. The peat powder is carried on the tender in a hopper with a conical bottom. Beneath the bottom is a pipe into which the powder falls, to be carried along by a current of compressed air to a nozzle opening into the fire-box. In the forepart of the fire-box is a small grate for a coal fire, which serves to ignite the peat powder. The consumption of coal in this grate is 3 to 4 per cent. of the weight of peat burnt. The comparative tests were between all coal on the one hand, and peat powder with this small proportion of coal on the other. Analyses of the peat and coal were as follows:

	Peat. Per Cent.	Coal. Per Cent.
Carbon	47	73·5
Oxygen	29·5	4·4
Hydrogen	4·5	8·6
Silicon	0·4	1·5
Nitrogen	1·1	1·2
Ash	3·2	6·2
Water	14·2	4·6

It was found that the ratio of the weight of peat to the weight of coal required to raise a certain amount of steam is 1·45 to 1.

III.—*COKE.*

Coke-Oven Practice.—G. B. Foxwell (*Paper read before the Sheffield University Gas and Coke-Oven Association*, December 1916; *Iron and Coal Trades Review*, December 1916, vol. 93, pp. 798–799) gives a general review of up-to-date coke-oven practice, with observations on the question of coal-washing.

By-Product Coke-Ovens in the United States.—The following table is given to show the number of by-product ovens of different types, both idle and active, completed and building in the United States at the

end of 1915 (*Iron and Coal Trades Review*, February 1917, vol. 94, p. 128):

	Completed.	Building.
Koppers	2104	959
United Otto	1957	124
Semet-Solvay	1689	54
Rothberg	281	...
Didier	150	...
Gas machinery	30	30
Klönne	27	...
Wilputte	18	...
Robert (flueless)	12	24
Total	6268	1191

By-Product Coke-Oven Plant.—A description is given (*Iron and Coal Trades Review*, December 1916, vol. 93, pp. 663–664) of the new coal-washery, coke-ovens, and by-product plant at Risca Colliery in Monmouthshire, with numerous illustrations.

Elimination of Sulphur in By-Product Coking.—C. C. Campbell (*Blast-Furnace and Steel Plant*, August 1916, pp. 368, 374) discusses the elimination of sulphur in by-product coking, showing the influence of sulphur on the quality of the coke and by-products, and the inadequacy of water as a desulphurising agent.

Low Temperature Distillation of Coal.—A. Pictet (*Revue Générale des Sciences*, October 1916, vol. 27, pp. 579–584) gives an account of the process of the distillation of coal at low temperature and *in vacuo*. Under a gross pressure of 15 millimetres, distillation begins at about 100° C. and is complete at 450° C., or little above the point at which it begins under ordinary atmospheric pressure. The products obtained are also of a different character from those yielded under ordinary pressure, in particular the tar and the resulting coke. The characteristics of all the products are described and their differences are pointed out.

Some notes are given (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 521) on the use of surplus gas from a low-temperature carbonisation plant for the purpose of generating electricity, and the various industrial applications of coal-tar pitch are considered.

Thermal Decomposition of Low Temperature Coal Tar.—D. T. Jones (*Journal of the Society of Chemical Industry*, vol. 36, 1917, pp. 3–7) has carried out investigations on the thermal decomposition of low temperature coal-tar.

Recovery of By-Products.—The report of the Chief Inspector of Alkali Works for the year 1915 shows that there has been a very substantial increase in the amount of sulphate of ammonia recovered at coke-ovens. The increase over 1914 amounts to 7976 tons. Approximately each ton of coal carbonised in by-product ovens yields 25 lb.

of sulphate of ammonia. This shows a steady growth in the number of by-product ovens, and as times become normal again it is more than likely that new installations will be erected to take the place of obsolete beehive ovens.

Very little has been done in the way of recovering cyanogen on gasworks and coke-oven plants. Only about four of the largest gasworks in the country operate cyanogen recovery plants, and not a single coke-oven plant. Cyanogen is invariably produced in the carbonisation of coal, although only in comparatively small quantities. It is essentially a high-temperature product, and is produced only at the expense of the ammonia. The conditions of ammonia production have been extensively studied, and it is fairly well established that the maximum production is reached at a temperature of about 850° to 900° C. When the carbonising temperature goes beyond that point interaction between the ammonia and the carbon occurs, resulting in the decomposition of the former and the formation of cyanogen.

One method of recovery frequently used is the following. Sulphate of iron is added to weak ammoniacal liquor precipitating ferrous sulphide. The solution containing the precipitate is then used in a washer to scrub the gas. The cyanogen combines with the iron forming a solution of ammonium ferro-cyanide, which can then be worked up into the usual form of Prussian blue. Another method is to wash the gas in a solution made by adding sulphur to ammoniacal liquor to form ammonium polysulphide (Am_2S_2). The cyanogen is again absorbed forming ammonium sulpho-cyanide, and is recovered as such. A considerable amount of cyanogen is also recoverable from the oxide of iron used for removing sulphuretted hydrogen from the gas. This, however, is a process which is carried out at only a few coke-oven plants, as it is not considered worth while to remove this impurity unless the gas is to be used in gas-engines, when the removal is an economic necessity.

Recovery of Ammonia.—It is by no means generally accepted amongst coke-oven owners that the newer semi-direct or direct processes for the recovery of ammonia offer any substantial advantages over the old indirect process (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 644). One reason for any preference is no doubt the continued difficulty of obtaining supplies of sulphuric acid for sulphate making. With the semi-direct and direct processes a large proportion of the ammonia is left in the gas, and if there is a shortage of acid this ammonia is lost, or else the plant must be shut down until acid is again available. In the direct process practically all the ammonia is in the gas, as no liquor is produced, there being no provision made either for cooling or scrubbing the gas. In some of the later direct plants the fixed ammonia is washed out and recovered as chloride, so that about 90 per cent. of the total ammonia—representing the whole of the free ammonia—remains in the gas.

Applications of Ammonia.—J. W. Turrentine (*Journal of Industrial and Engineering Chemistry*, October 1916, vol. 8, pp. 923–926) points out that for times of peace America has a supply of nitrogen compounds adequate for both fertilising and explosives manufacture. The supply includes imported nitrate which is adequate for the manufacture of munitions and by-product ammonia which contributes to the fertilising industry. In time of emergency, should importation be prohibited, the by-product ammonia could be withdrawn at once from the fertilising industry and applied to the munitions industry. Accompanying this development a conservation is taking place worth many millions annually to the American nation.

Coal and Coke By-Products as Sources of Fixed Nitrogen.—H. C. Porter (*Paper read before the New York Meeting of the American Chemical Society; Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 470–475) points out that the increase in capacity for ammonia production at by-product coke plants due to new establishments and those now building, amounts in the United States alone to 46,400 tons of ammonia (NH_3) per annum. Gasworks, other than coke-ovens, can produce a further 12,500 tons. The total capacity at the close of 1917 is estimated at 126,500 tons, capable of producing 404,000 tons of 95 per cent. nitric acid. While fertilisers are not indispensable in the United States, their use is valuable, but apart from this, war emergencies are amply provided for, as are also the requirements for refrigeration purposes. A table is given showing the by-product coke plants in the United States at present, with their coal consumptions and ammonia production. The various processes employed for the recovery of fixed nitrogen as a by-product of coal carbonisation are likewise discussed and compared.

Recovery of Benzol from Gas.—F. W. Sperr, Jun. (*Paper read before the American Institute of Chemical Engineers*, January 1917; *Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 135–140), points out that one of the most noteworthy recent achievements of chemical industry in America has been the rapid recovery of benzol from coal gas, an industry that had previously lagged behind in development. In January there were about forty plants in operation in connection with by-product coking, and approximately 30 million tons of coal can be treated annually. This would give a light oil yield of not less than 40,000,000 gallons. The uses of benzol, apart from war needs, are numerous, benzene itself being the indispensable basis of the aniline dye industry, whilst the manufacture of synthetic phenol is far outstripping that of carbolic acid from coal tar. Toluene is the basis of benzaldehyde, of saccharin, and of benzoic acid, while the demands of the automobile industry alone are such as to preclude any possibility of destructive competition between benzol and gasoline. The principles of benzol recovery are then described

and the operation of a recovery plant detailed. Upkeep is inexpensive and the labour required small. The calorific value of the debenzolised gas is somewhat lower, the loss representing about 5·8 per cent., but this loss equals in value only about one-eighth of that of the benzol extracted.

In a paper read before the Midland Junior Gas Association, T. F. E. Rhead (*Iron and Coal Trades Review*, February 1917, vol. 94, p. 157) gives the following conclusions relating to the problem of the extraction of crude benzol from coal gas using creosote as a washing medium:

(1) The efficiency of washing is greatly improved by using a cold oil—at say 15° C.—provided the creosote keeps sufficiently fluid. (2) The lighter oils in creosote—180° to 220°—help the washing process by lessening the viscosity of the creosote, but are objectionable in that they are readily distilled out by steam and contaminate the crude benzol. (3) Naphthalene helps to lessen the viscosity, and thereby helps the washing; but it is very objectionable in that it prevents good extraction of naphthalene from the gas, and may even add some to the gas under certain conditions of quantity and temperature. (4) Creosote fractions boiling above 300° greatly increase the viscosity, and are very objectionable if present to any extent. (5) A good creosote should remain as fluid as possible at 10° to 15°, give little oil distillate when steam distilled, and have as low naphthalene content as possible. (6) Greatly improved cooling of debenzolised oil from the crude still is obtained by using a creosote of which the viscosity rises very little when cooled to 10° to 15°, and better temperatures are obtained for benzolised oil entering the crude still. (7) The efficiency of washing is greatly improved by increasing the intimacy of contact between the oil and gas. Washers on the spraying or atomising principle appear to offer the best field for development in this direction —namely, an increase of surface per volume of washer and minimum back pressure. (8) When using mixtures of blast-furnace and coal-tar creosotes specific gravity is no criterion as to whether a creosote is "spent" or not, and its magnitude. Viscosity is the best test, and should be between 8 to 9, with a maximum of 10 (rape oil = 100). (9) A sufficient quantity of creosote should be in circulation to prevent the light oils taken out and contained in the crude benzol in stock leaving a creosote of high viscosity. If light oils are sold with crude benzol, then either the creosote must be changed more frequently or the equivalent quantity of similar light oils added to take the place of those in the crude benzol.

A description is given (*Paper read before the Manchester District Institution of Gas Engineers*, October 1916; *Iron and Coal Trades Review*, November 1916, vol. 93, pp. 576–577) of the benzol and toluol recovery plant at the gasworks, and the by-product plant of the Mitchell Main Colliery Company. The latter plant comprises forty Simon-Carves ovens erected in 1907 and five erected in 1911. The

slack is brought from the washery on the colliery site about a quarter of a mile away by means of an aerial bucket conveyor. A feature of the plant is the system of disposing of the discharged coke, through loading holes in the flat discharge bench, direct into railway wagons on the line underneath the bench.

R. Lessing (*Journal of the Society of Chemical Industry*, vol. 36, 1917, pp. 103–107) gives an illustrated description of a new method for the recovery of benzol from coal gas.

J. A. Wilson (*Journal of Gas Lighting*, 1916, vol. 136, pp. 447–449; *Journal of the Society of Chemical Industry*, vol. 36, 1917, p. 24) deals with benzol recovery from gas as carried out at the coke-oven plant of the Staveley Coal and Iron Co., Ltd.

D. Bagley (*Journal of Gas Lighting*, 1916, vol. 136, pp. 491–493; *Journal of the Society of Chemical Industry*, 1917, vol. 36, p. 24) gives a description of the Carl Still system of recovering benzol from coke-oven gases.

The Rectification of Benzol.—W. N. Drew (*Transactions of the Institution of Mining Engineers*, 1917, vol. 53, pp. 10–16) gives an account of modern practice of the rectification of benzol. Some consideration is given to the necessity for an organisation to supply the market with benzol as motor spirit after the war, the estimated requirements being at least 40 million gallons per annum.

Manufacture of Ammonium Nitrate.—E. K. Scott (*Journal of the West of Scotland Iron and Steel Institute*, 1915–16, vol. 23, pp. 119–141) describes the manufacture of ammonium nitrate by electric power. Nitric oxide is first produced from atmospheric air in an electric furnace of the author's own design, and the conversion of the oxide into nitric acid is carried out in an accessory chemical plant. The products of nitric acid are enumerated.

E. K. Scott and T. Twynam (*Ibid.*, pp. 143–153) describe the production of synthetic nitric acid, with utilisation of slags and waste gases.

Nitration of Toluene.—E. J. Hoffman (*U.S. Bureau of Mines*, Technical Paper 146, 1916, pp. 1–32) gives the results of experiments in the preparation of trinitrotoluene from toluene obtained in the manufacture of water-gas. The theory of toluene nitration is set forth and the technical methods for the manufacture of trinitrotoluene are reviewed, with a summary of the most favourable method for its preparation.

Growth of By-Product Industry in the United States.—According to a report issued by the U.S. Geological Survey (*Journal of the Society of Chemical Industry*, 1916, vol. 35, p. 955) the value of the by-products recovered from coke-ovens in 1915 was nearly $30,000,000 as com-

pared with \$17,500,000 in 1914. The greatest increase was in benzol products, the value of which increased from less than \$1,000,000 in 1914 to more than \$7,760,000 in 1915. The quantity of coal carbonised in by-product recovery coke-ovens in 1915 was 19,500,000 short tons. The increase in by-product coking has been very great since the beginning of 1916, and production is far in excess of the 1915 figures.

Coke as Boiler Fuel.—J. B. C. Kershaw (*Engineer*, January 19, 1917, vol. 123, pp. 51–52) discusses the use of coke and coke-breeze for steam raising. The conditions of combustion and forms of grate are considered and the results obtained with coke firing are given.

Fuel Value of Coal Tar Pitch.—The London Coke Committee have issued (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 545) a circular on the question of the value of coal tar pitch as fuel, drawing attention to the claims of a specially designed form of fire-bar.

Coke-Oven Accidents.—A. H. Fay (*U.S. Bureau of Mines*, Technical Paper 151, 1916, pp. 1–18) reports on coke-oven accidents in the United States during 1915. Statistics of accidents, classification of injuries, and causes of accidents are tabulated and reviewed. The production of coke for the five years 1910–1914 is given.

Coke Industry of New South Wales.—A general report on the coke industry of New South Wales has been prepared by L. F. Harper and J. C. H. Mingaye (*New South Wales, Department of Mines, Mineral Resources*, Bulletin No. 23, 1916). The coke production in the State was 417,753 tons in 1915, having doubled since 1909. The work is a statistical record with chemical analyses of coals used, coke produced and ash contents, with crushing tests, and notes on by-product recovery.

IV.—*LIQUID FUEL.*

Origin of Petroleum.—C. Richardson (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 25–27) advances the theory that the origin of petroleum is to be attributed to the relations of surfaces and films, that is to say, of films of certain types of natural gas to the surfaces of the solids with which they are in contact. The asphalt of Trinidad is adduced in support of this theory. It would appear that a petroleum, existing at considerable depth, is converted into solid form by coming in contact and being thoroughly emulsified with an aqueous paste of colloidal clay and sand. The clay and sand occur as a mud in a spring through which the oil breaks out before reaching the surface. In certain fields natural gas occurs, unassociated with petroleum. In this case it must be assumed that the gas does not

remain in contact with the "sands" for a sufficient time to accomplish the transformation, or that the surfaces are not of the area or character to condense the gas to petroleum, the time factor being an important one.

D. Hager (*Bulletin of the American Institute of Mining Engineers*, No. 122, 1917, pp. 195–198) deals with the evidence afforded by the Oklahoma oil-fields as to the anticlinal theory. Nearly all the known fields are on well-developed folds. Lensing of the sands and cementation have both been factors in favouring accumulation, but well-pronounced folding has influenced most of the fields. It may be regarded that the anticlinal theory completely harmonises with all that is known respecting the Oklahoma fields in the development of which the geologist has had a highly important share.

The Oil-Shales of Norfolk.—W. Forbes-Leslie (*Paper read before the Institution of Petroleum Technologists*, October 1916; *Engineer*, October 1916, vol. 122, pp. 347–348) gives an account of the Norfolk oil-shales, their physical character and chemical composition. A seam on the banks of Puny Drain, south of King's Lynn, is 7 feet thick and yields 50 to 51 gallons of oil per ton. Several other seams are capable of economic development.

Oil-Shale Industry of Scotland.—The position and developments of the Scottish oil-shale industry are reviewed (*Engineer*, March 1917, vol. 123, pp. 221–222, 274–275). The resources, methods of mining, and particulars of production are stated.

Fuel Deficiency in Russia.—An article has appeared (*Petroleum Review*, vol. 36, February 1917, pp. 145–146) on the deficiency of fuel in Russia. The production of petroleum has recently permanently decreased and cannot be reinforced without bringing in the exploitation of new petroliferous areas. The large increase in the production on the secondary areas of the Baku district has not yet covered the deficiency in the production on the four main Baku areas. The production of Russia's second source of power and heat, coal, has also decreased to a very considerable extent, owing to the enemy occupation of the Dombrova coal-fields and the total cessation of imports. The new areas ready for exploitation are in Siberia, this territory having become of very great importance, being rich in every kind of natural wealth, including fuel. The Western Siberian coal districts include the following areas: the Kirgiz steppes, extending along the river Irtish; the Enisei deposits, extending along the River Enisei and its affluents; the Kusnetz district, situated in the northern part of the Altai province and to the south from Tomsk; the eastern Ural deposits, and the Tcheremkhov district in the Irkutsk province. Only the first three are at present under exploitation, but all are, however, of great importance and capable of yielding enormous tonnages per year.

Petroleum in Japan.—The total output of crude oil in the Japanese oil-fields during the first six months of the present year amounted to 225,811,800 litres (*Petroleum Review*, October 1916, vol. 35, p. 296).

Petroleum in the Philippines.—An account is given (*Petroleum Review*, November 1916, vol. 35, pp. 375–376) of the oil-fields of Tayabas Peninsula. The crude petroleum has a very light specific gravity, and only two or three fields in the world produce an oil comparable with it. It is very desirable for distillation, since it contains an unusually high percentage of gasoline and kerosene, and it should accordingly command a high price in the market. Dr. G. I. Adams, geologist of the Division of Mines of the Philippine Bureau of Science, is of opinion that while prospecting for oil is always attended with a certain degree of risk, the conditions in the Tayabas Peninsula are favourable to the profitable development of the fields.

Oil-Shales in Natal.—A. L. Du Toit has made a report for the South African Geological Survey (*Mining Magazine*, 1916, vol. 15, pp. 358–360) on the oil-shales of Impendhle County, Natal. These shales are found at the head of the Loteni and Umkomaas rivers, about fifty miles west of Pietermaritzburg, and in the foot-hills of the Drakensberg. Details are given regarding the formation of the strata and illustrations showing characteristic sections of Natal oil-shales.

Petroleum in Canada.—J. Stansfield (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, pp. 371–398) gives a historical review of the Petrolia oil-field, Ontario. The oil-fields of Oil Springs and Petrolia lie in the south-western peninsula of Ontario, and the first flowing well was struck in 1862 by J. Shaw. The geology of the region is fully dealt with, and the drilling practice is described. The oil industry of Petrolia has been especially remunerative on account of the very small cost of drilling the wells, the easy manner in which they can be grouped and pumped from one central power station, and the low cost of producing the oil.

Recent reports from the Southern Alberta Oil Company's No. 2 well state that a very promising oil spring has been encountered at 3100 feet (*Petroleum Review*, January 1917, vol. 36, p. 29). It is stated that there are 1700 feet of oil in the well, and it is estimated from tests with the bailer that the oil is flowing in at the rate of about 20 barrels a day. The Southern Alberta Company is increasing its tankage to about 5000 barrels capacity.

It is reported from Edmonton that five tests drilled in the Viking district, about 75 miles from that city, for gas, have all shown oil in commercial quantities. The original tests were undertaken by the Northern Alberta Development Company, which intended to pipe gas from Viking to Edmonton.

An account is given (*Petroleum Review*, November 1916, vol. 35, pp. 415–416) of the petroleum resources of Canada, with special reference to the New Brunswick field.

Reference is also made (*Petroleum Review*, March 1917, vol. 36, pp. 207–208) to the oil and gas sands underlying Alberta.

Petroleum in the United States.—G. C. Matson (*U.S. Geological Survey*, Bulletin 619, 1916, pp. 1–62) describes the geological character of the Caddo oil and gas field in Louisiana and Texas. Drilling on the east side of the field has been successful in the shallow sand at the east end of the Vivian anticline, and there is much territory which will doubtless prove valuable for oil.

The possibilities of further development of the oil and gas fields in north central Montana are reported on by E. Stebinger (*U.S. Geological Survey, Economic Geology*, Bulletin 641–C, 1916, pp. 49–89).

K. C. Heald (*Ibid.*, Bulletin 641–B, 1916, pp. 17–47) has studied the oil and gas geology of the Foraker Quadrangle, Oklahoma.

W. A. English (*U.S. Geological Survey, Economic Geology*, Bulletin 621–M, 1916, pp. 191–215) reviews the geology and oil prospects of Cuyama Valley, California. The region lies between two of the richest oil-fields of the State. On the whole the prospect of obtaining more than small quantities of oil in this area is not promising.

R. W. Pack (*Paper read before the Geological Society of Washington*, March 22, 1916) discusses the geological and structural features of the San Joaquin Valley oil-fields.

M. W. Ball (*Petroleum Review*, December 1916, vol. 35, p. 514) deals with the necessity for the conservation of oil and natural gas in the United States.

W. A. Williams (*Petroleum Review*, November 1916, vol. 35, p. 398), petroleum technologist of the United States Bureau of Mines, has planned several important investigations relating to petroleum and natural gas, including the study of the most efficient drilling methods with a view to reducing underground waste from infiltration waters and the dispersion of oil and gas into open or porous formations to a minimum, and the promotion of the most efficient production methods with a view to increasing the percentage of recoverable oil. Another investigation relates to the most efficient methods of utilising petroleum and its products, and to the best methods of storing and transporting petroleum and extracting motor spirit from gas.

H. G. James (*Petroleum Review*, October 1916, vol. 35, pp. 287–289, 315–316) gives a comprehensive review of the oil-refining industry of the United States. A list is given of the oil and petroleum refineries; of the latter there are 302, with a total capacity in excess of 1,000,000 barrels a day. The total daily crude production of petroleum in 1915 was 834,000 barrels a day. Eleven of these petroleum refineries are in course of construction and 26 are idle, leaving 265 in active operation. An additional list shows 40 new refineries building or projected. They

will bring the refinery capacity of the United States up to 1,193,245 barrels a day or more.

P. T. Moore (*Petroleum Review*, January 1917, vol. 36, pp. 55–56, 75–76, and 88) reviews the mid-continental oil industry of the United States in 1916.

Petroleum in Trinidad.—Experts for the principal companies in Trinidad are fully satisfied as to the oil-bearing capacity of a large part of the island (*Petroleum Review*, October 1916, vol. 35, p. 296). Quantities are stored awaiting freight opportunity, and many proved producing wells are capped pending further storage room. The quantity exported in 1915 was 14,113,855 gallons, which was largely exceeded in the first six months of 1916.

Petroleum in Mexico.—T. H. Bevan (*Petroleum Review*, November 1916, vol. 35, p. 365) gives a detailed account of the petroleum industry of Mexico.

Petroleum in Peru.—The condition of the petroleum industry in Peru is reviewed (*Boletin del Cuerpo de Ingenieros de Minas del Peru*, No. 82, 1916, pp. 31–45). The report covers the year 1914, in which the production was 244,923 tons, or about 23,000 tons less than in 1913. Wells to the number of 703 were at work in four provinces.

Petroleum in Chili.—Recent discoveries of oil in the territory of Magellan have created much interest, as hitherto Chilian oil has been found only in the northern and central sections of that country. The National Association of Manufacturers (Sociedad de Fomento Fabril), in a recent bulletin, states that geological experts have made tests of the oil in Magellan and pronounce it equal in quality to that found in Argentina, and the extent of the deposits appears to rival that of the famous Comodoro Rivadavia fields (*Petroleum Review*, November 1916, vol. 35, p. 374).

Petroleum Recovery from Unconsolidated Sands.—W. H. Kobbé (*Bulletin of the American Institute of Mining Engineers*, No. 120, 1916, pp. 2253–2276) discusses the problems connected with the recovery of petroleum from unconsolidated sands, under the main subdivisions of drilling, extracting the oil and sand, the quantity of sand produced, and the oil separation and sand disposal.

Use of Mud-laden Fluid in Oil and Gas Wells.—J. O. Lewis and W. F. McMurray (*U.S. Bureau of Mines*, Bulletin 134, 1916, pp. 1–86) report on the use of mud-laden water prepared from clay for the prevention of waste in oil and gas wells. The action of the mud-fluid is entirely dissimilar to that of clear water. It enters the porous strata for a short distance and deposits mud, which clogs the openings and prevents further inflow of oil or gas.

W. F. McMurray and J. O. Lewis (*Petroleum Review*, 1916, vol. 35, pp. 435–436, 445–446, 487–488, 527–528; 1917, p. 18) deal with underground wastes in oil and gas fields, and suggested methods of prevention. The article is fully illustrated.

Sulphur in Petroleum Oils.—F. M. Perkin (*Journal of the Institution of Petroleum Technologists*, 1917, vol. 3, No. 11, pp. 227–242) reviews the conditions under which sulphur occurs in petroleum and oil-shales. It is stated that the high sulphur content in oils occurring at various places in the Empire, such as in the English Kimmeridge Clays, prevents the use of these resources. A process has been developed in which ammonia is used at high temperatures and pressures. The reaction between the ammonia and the thio compound releases the sulphur as sulphuretted hydrogen. It is found also that this reaction will in some cases hydrogenise the compound, that is to say, add atoms of hydrogen.

By-Products of Petroleum.—G. Egloff and T. J. Twomey (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 245–250, 523–529) consider the influence of the time factor on the formation of aromatic hydrocarbons from a paraffin base oil. Broadly speaking the oil recovered decreases as the time factor increases, as does its specific gravity. The conditions vary from time to time, and the percentage recoveries of benzene, toluene, and xylene at varying times and rates of distillation are given, both in the text and diagrammatically.

In collaboration with R. J. Moore, Egloff (*Ibid.*, pp. 340–350) also discusses the effect of aluminium chloride upon the formation of gasoline and unsaturated and aromatic carbons from a naphthalene base oil.

Fractionation of Paraffin Oils.—G. Egloff, T. J. Twomey, and R. J. Moore (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 523–529) have continued their investigation of the products formed by the decomposition of petroleum oils under varying conditions of heat and pressure. The end products yielded by a paraffin base oil are compared with the proportion of the same products yielded by a naphthene oil.

Chemistry of the Paraffin Hydrocarbons.—G. Egloff and R. J. Moore (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 47–51) show that, contrary to the usually accepted view, stability is not a direct function of the paraffin chain molecule. The maximum stability is at about 250° C., representing the compounds ($C_{12}H_{26}$ to $C_{15}H_{32}$) minima at the lowest boiling points (C_5H_{12} to C_9H_{20}) and the highest boiling points ($C_{19}H_{40}$ to $C_{23}H_{48}$). The above compounds have been isolated from a Pennsylvania paraffin-base petroleum oil. The general belief that the simpler petroleum hydrocarbons are stable at

much higher temperatures than those of higher molecular weight is shown, by the accumulated evidence given, to be untenable.

Oil-Shale as a Source of Gasoline.—The extraction of gasoline from oil-shale as a competitive process to its extraction from petroleum is noted as a future industrial possibility (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 71–72). In this connection the prospects of the Colorado and Utah shales in the United States, and those of Rhodesia and other localities in South Africa, are noted. The African oil-shale when rich is very tough, burns on ignition, and resists erosion to a remarkable extent. The Colorado oil-shale yields a crude oil which gives 10 to 15 per cent. of gasoline. It is, moreover, a valuable source of ammonium sulphate. The equipment of an oil-shale plant is somewhat high, and it is doubtful whether, on a small scale, the industry would be remunerative.

An experimental plant will, it is stated (*Ibid.*, pp. 180–181), be shortly installed near De Beque, Mesa County, Colorado, for the extraction of oil from the local shales. A description of the proposed plant and of the method to be practised are given.

Standard Tables for Petroleum Oils.—Standard tables have been prepared for finding the density of petroleum oils at a standard temperature when the density at another temperature is known (*Bureau of Standards, Washington*, Circular No. 57, pp. 1–64, 1916).

H. W. Bearce and E. L. Peffer (*Bureau of Standards*, Technologic Paper No. 77, 1916, pp. 1–26) give an account of the experimental work on which the standard tables for petroleum oils are based, with a detailed description of the methods and apparatus employed in the determination of the density and thermal expansion of petroleum oils from the various oil-fields of the United States.

Spontaneous Ignition of Liquid Fuel.—H. Moore (*Journal of the Society of Chemical Industry*, 1917, vol. 36, pp. 109–113) considers the spontaneous ignition temperatures of liquid fuels for internal combustion engines.

Determination of the Calorific Power of Oil by the Coal Calorimeter.—O. Bertoya, Jun. (*Mechanical Engineer*, 1917, vol. 39, p. 314), discusses the question of using a coal calorimeter for determining the calorific power of oil. The general principle utilised is to absorb the oil by means of suitable materials, combustible or otherwise, and then to treat the whole as an ordinary coal sample. There are certain methods which are more suitable than others for certain types of calorimeters. Three of the best known types, the Thompson, Darling, and bomb calorimeters are taken and a suitable method given for each, and judging from the results of experiments with these it is found that good work could be done with any pattern of coal calorimeter on the market.

Liquid Fuel for Metallurgical Furnaces.—In the plant of the Compañia Fundidora de Fierro y Acero of Monterrey, Mexico, oil is now used as fuel for the boilers, open-hearth furnaces, and the furnaces in the rolling-mills (*Iron and Coal Trades Review*, March 1917, vol. 94, p. 355). An analysis of the crude Mexican oil in the market gives the following percentages: Carbon, 82·70; hydrogen, 12·20; oxygen, 0·40; nitrogen, 1·70; sulphur, 3·00. Its density is 16° to 20° Bé.; its average specific gravity, 0·936. Its calorific value is 4·680 heat units. The oil is consumed at the following rates in the different furnaces. The open-hearth furnaces turn out three charges in twenty-four hours, and consume 147 litres (32·34 gallons) per metric ton of finished steel when dealing with cold charges, and 121 litres (26·62 gallons) per ton, with four charges per twenty-four hours, when one-half of each charge consists of molten metal, and the other half scrap. The proportion of the oil consumption to the former gas coal consumption is 473 litres (104 gallons) of oil to 1 metric ton of coal, the heating value of which was 2918 calories. The furnaces in the rolling-mills showed an exaggerated consumption, as the mills were only working twelve hours a day, and the furnaces had to be kept alight for part of the night. Moreover, the bar mills only received cold blooms and billets, and some of the blooms received by the joist mills were also cold. The oil consumption in the blooming-mill, therefore, varied between 60·5 and 83·2 litres (13·31 and 18·30) gallons per metric ton of blooms. The proportion to the gas coal formerly used was 492 litres (108·24 gallons) of oil to 1 ton of coal. In the rail and joist mill 87 litres (19·14 gallons) of oil were consumed per metric ton of rolled products, and 85·2 litres (18·74 gallons) per ton in the bar-rolling mill. The oil consumed in producing steam for the vaporisers is included in the fuel for boilers. There are thirteen Babcock & Wilcox 400 h.p. boilers, the oil consumption of which can only be given in proportion of the coal formerly burnt; it amounts to 548·8 litres (121 gallons) of oil for every ton of coal formerly used. In this quantity the amount of oil for producing steam for the vaporisers is included.

Use of Fuel Oil.—Some experiments in natural draft oil burning are illustrated and described by L. R. Ford (*Journal of the American Society of Naval Engineers*, 1916, vol. 28, pp. 641–655; *Journal of the American Society of Mechanical Engineers*, 1916, vol. 38, pp. 830–831).

B. Stoughton (*Petroleum Review*, October 1916, vol. 35, pp. 313–314; *Iron and Coal Trades Review*, 1916, vol. 93, p. 480) describes a method of using crude oil for cupola melting by which three parts are saved of the quantity of coke which is generally burned in the ordinary process. The oil and air are conveyed to an ignition chamber in the cupola by two pipes. The oil flame is started in the ignition chamber and enters the cupola in contact with the coke bed, which is

maintained in an incandescent state by an independent supply of air admitted through tuyeres underneath the ignition chamber. The cupola is first filled with coke up to the melting zone, and the coke is brought to a state of incandescence in the usual way. The amount of coke used and the method of getting it red hot is the same in the oil process as in the usual coke process. On top of the bed the first charge of iron is then placed, which also is the same depth as in coke melting; then comes a layer of coke which is only one-quarter the amount ordinarily used. The oil is atomised into ignition chambers surrounding the cupola, and is there mixed with air for its combustion. The flame from the burning oil enters the cupola and comes in contact with the bed of coke by which its combustion is hastened and completed. The result is an intensely hot oil flame by which the bulk of the melting is done.

V.—*NATURAL GAS.*

Natural Gas in the United States.—E. W. Shaw, G. C. Matson, and C. H. Wegemann (*U.S. Geological Survey*, Bulletin 629, 1916, pp. 1–129) report on the natural gas resources of parts of north Texas, some notes being included on the gas-fields of central and southern Oklahoma. In northern Texas the supply of gas to the cities drawing upon it is estimated at the present rate of consumption to last about six and a-half more years. The original quantity in the Petrolia field was 120 billion cubic feet, of which about 37 billion have been delivered to consumers.

The deep-seated reservoir supplies of gas and oil in the Cleveland district of Ohio are discussed by F. R. van Horn (*Bulletin of the American Institute of Mining Engineers*, No. 121, 1917, pp. 75–86). The term reservoir gas is applied generally to a high-pressure gas occurring in large volume at a definite horizon. The highest authentic rock pressure reported in the Cleveland field was a well of the National Carbon Company which registered 1120 lb. per square inch. The chief gas-producing territory as outlined by present geological indications is in the Berea quadrangle, and the most successful drilling is being done to the south-west of Cleveland across that region.

Natural Gas in Canada.—Some account is given (*Petroleum Review*, April 1917, vol. 36, pp. 249–250) of the occurrence of petroleum and natural gas in New Brunswick.

An account is given (*Petroleum Review*, October 1916, vol. 35, pp. 307–309) of the development of natural gas in the Medicine Hat Field with a history of well-drilling operations.

Viscosity and Specific Heat of Natural Gas.—R. F. Earhart (*Journal*

of the American Society of Mechanical Engineers, 1916, vol. 38, pp. 888–890) presents a study of the ratio of the specific heat and the coefficient of viscosity of natural gas from ten gas-fields in the United States.

Apparatus for the Manufacture of Gasoline.—C. P. Bowie (*U.S. Bureau of Mines*, Technical Paper 161, 1916, pp. 1–16) describes the construction and operation of a single tube cracking furnace for making gasoline. Particulars of the plant are given in great detail, with drawings and photographs.

VI.—*ARTIFICIAL GAS.*

Gas-Producers.—A detailed illustrated description has appeared (*Mechanical Engineer*, 1917, vol. 39, p. 143) of a design of intermittently operating gas-producer recently patented by Messrs. Dellwik-Fleischer, of the class in which the blast air is only passed through the column of coke in the lower portion of the producer.

Gas-Producer for Bituminous Fuel.—O. C. Berry (*Journal of the American Society of Mechanical Engineers*, 1916, vol. 38, pp. 973–978), after studying the requirements of a gas-producer using bituminous fuel, has brought out a type called the "recirculating" gas-producer. The coal is charged through a trap at the top, the only air inlet being below the grate. The combustion all takes place above the grates. The finished gas is drawn off from the fuel column into an annular chamber, which is formed in the firebrick lining of the producer. The products of distillation and the other recirculated gases are drawn into the pipe by a steam blower and then delivered into the header, and from there into the distributor. This distributor is so constructed as to deliver an equal amount of the recirculated gases to every part of the grate area, and in such a way that the gas burns as it mixes with the air, largely in the lower part of the combustion zone of the fuel.

Wood-Gas Producer.—E. Huntley (*Mining Magazine*, 1916, vol. 15, pp. 280–281) describes a new wood-gas producer, designed for the Hampden mine and smelting plant. The producers previously used had burnt charcoal, but this method being costly, experiments were undertaken with firewood. The new producer was designed on the plan of having two zones of action, an upper zone in which the oils, tar, and other hydrocarbons are converted into gas and the wood into charcoal, and a lower zone in which the charcoal is attacked. The gases from the two zones are withdrawn through a port in the upper part of the lower zone. Illustrations are given showing the general construction of the new producer.

Grate for Gas-Producers.—P. A. J. Cousin (*Mechanical Engineer*, 1917, vol. 39, pp. 19–20) has patented a design of grate for gas-producers particularly applicable to producers of the type in which the blast distributor is furnished with submerged blast outlets. With this arrangement the gas-producer is enabled to work with natural draught if necessary should the fan or blower employed with the producer have to be stopped for any reason, as, for example, through the failure of the supply of energy that is given to the fan. A detailed description of the grate is given, accompanied by diagrams.

Gas-Producer Practice.—F. Denk (*Blast-Furnace and Steel Plant*, January 1916, pp. 23–24) considers the advantages to be gained in gas-producer operation through the blowing of air and steam separately by mechanical means instead of using a steam injector.

D. R. Steuart (*Journal of the Society of Chemical Industry*, 1917, vol. 36, pp. 167–176) deals with the brown-coal distillation industry of Germany.

Producer-Gas as Boiler Fuel with By-Product Recovery.—T. R. Wollaston (*Engineer*, August 25, 1916, vol. 122, p. 161) proposes the application of producer-gas to the firing of boilers as an economical combination, provided the by-products are recovered. With high-efficiency boilers such as the Bonecourt boiler such an arrangement would be profitable if the ammonium sulphate were recovered and if provision were made for the manufacture of sulphuric acid.

The Moll burner and safety shut-off valve for gas-fired boilers is described and illustrated (*Iron and Coal Trades Review*, February 1917, vol. 94, p. 213).

Use of Coal Gas for Power Purpose.—H. M. Thornton (*Journal of the Royal Society of Arts*, April 1917, vol. 65, pp. 405–429) has written an article on the application of coal gas to industry in war time and its national importance.

Gas Furnace Firing.—The advantages and disadvantages of the three usual systems of furnace-firing by gas—natural draft, gas at ordinary pressure, and air-blast and high-pressure gas with air at atmospheric pressure—are discussed in a paper by J. McIsaac (*Iron and Coal Trades Review*, February 1917, vol. 94, p. 122) read before the Foremen's Association of the Glasgow Gas Department.

Utilisation of Tar from Gas-Producers.—F. Fischer and W. Schneider (*Stahl und Eisen*, 1916, vol. 36, pp. 549–554; *Journal of the Society of Chemical Industry*, 1916, vol. 35, p. 1146) deal with the utilisation of tar from gas-producers, using lignite as fuel.

Enrichment of Blast-Furnace Gas with Coke-Oven Gas: "Compound" Gas.—W. Zimmermann (*Iron and Steel Review; Journal of*

Industrial and Engineering Chemistry, January 1917, vol. 9, p. 99) states that blast-furnace gas can be improved by blowing it through a coke-oven. By experiments made with a small Otto coke-oven, he found that the gas mixture thus produced (for which he suggested the name of compound gas) contained less carbon dioxide and less nitrogen than when the two gases were mixed cold in the usual way. At the same time it contained more hydrocarbons both light and heavy and, consequently, had a higher calorific value—in one case as much as 13·6 per cent.—as compared with the cold mixture. Moreover, passing the furnace gas through the oven over the coked mass lowered the temperature of the nascent coke-oven gas and prevented the decomposition of some of the ammonia already formed, a considerable amount of which was lost, especially during the last hours of the carburising period. According to the author's results, the yield of ammonia was increased by 25·2 per cent., as compared with that obtained from coke-oven gas in the ordinary way. The cooling of the coke-oven did not increase the amount of gas fuel required nor prolong the carburising period, which usually takes thirty-six hours, nor did the blowing of blast-furnace gas through the coke-oven have any effect on the quality of the coke produced.

Gas-Engines.—An illustrated description has appeared (*Petroleum Review*, January 1917, vol. 36, p. 25) of an oil and gas engine of new design brought out by the Western Gas-Engine Corporation of Los Angeles. These engines are especially adapted to the use of California low-grade fuel oils, as well as natural gas. Seven sizes have so far been developed, namely, 80, 100, 120, and 160 horse-power, in two-cylinder units, and 200, 240, and 320 horse-power, in four-cylinder units. A noteworthy feature of the construction is that the assembled or completed engines mentioned above are composed of standard single cylinder units, so that the purchaser is at all times assured of repair parts being readily obtained.

VII.—*COAL–MINING*

Shaft-Sinking.—J. W. Doty (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, pp. 270–292) discusses methods of sinking mine shafts of great depth through water-bearing strata, describing a number of instances of shaft-sinking with plans and sections of the work.

The widening of the upcast shaft at Tinsley Park Colliery is described by H. J. Atkinson (*Paper read before the Midland Institute of Mining, Civil, and Mechanical Engineers*, October 5, 1916; *Iron and Coal Trades Review*, 1916, vol. 93, p. 424).

G. Blake Walker (*Paper read before the Midland Institute of Mining, Civil, and Mechanical Engineers*, November 1916; *Iron and Coal Trades Review*, November 1916, vol. 93, p. 612) publishes an account

of making a shaft upwards. The shaft was 10 feet in diameter, lined with brickwork, with the top arched over. Two years ago it was desired to continue this staple pit to the Fenton Seam 20 yards above. The operations of excavation are described.

Use of Cement in Collieries.—J. Blandford (*Transactions of the Institution of Mining Engineers*, 1917, vol. 53, pp. 22–29) describes the applications of cement in coal-mine workings. The special objects to which cementation has been successfully applied are shaft-sinking or level driving, underground dams, underground fires, defective boreholes, and defective shaft-lining. The François system of cementation is especially referred to.

Mine Timber.—J. Mitchell (*Paper read before the Midland Institute of Mining Engineers*, December 1916; *Iron and Coal Trades Review*, December 1916, vol. 93, pp. 729–730) discusses causes of decay of timbers in coal-mines. No computation of the relative amount of wastage of timbers caused by the various factors has been made in this country, but in the mines of the U.S.A. it has been estimated that 5 per cent. was due to wear, 20 per cent. to breakage under pressure or squeeze, 25 per cent. to miscellaneous causes, and the remaining 50 per cent. directly or indirectly to fungal attack. The various types of fungi which attack mine timber are enumerated, with indications of their particular characteristics.

Steel Props in Use at Collieries.—A new type of steel prop in use at Arley Colliery, Warwickshire (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 482) consists of a steel tube 3 inches in diameter, screwed at the lower end to fit into a cast-iron foot. This foot is recessed on the under side for a depth of 6 inches by 5 inches in diameter. A wall divides this recess from the upper or screwed portion, this wall forming a solid bedding for the tube when it is screwed home. A collar formed of a casting with a rounded upper surface has its lower end made to fit into the upper end of the tube, where it is secured by means of a through bolt. An illustration of the prop is given.

Subsidence in Mining.—L. E. Young and H. H. Stoek (*University of Illinois Bulletin*, No. 91, 1916, vol. 13, pp. 1–205) have prepared an exhaustive report on the question of subsidences in mining. The memoir consists largely of an abstract of all the literature on the subject, which is dealt with under the headings: Nature and extent of subsidence problems; records of damage to surface; effect in water supply; geological conditions affecting subsidence; protection of objects on the surface; restoring damaged lands; and legal considerations. The bibliography at the end of the report covers twenty-five pages.

Equipment of Collieries.—An illustrated description is given (*Iron and Coal Trades Review*, December 1916, vol. 93, pp. 693–695) of

Coedely Colliery, Glamorganshire, with special reference to the surface equipment and winding plant. The plant includes an extensive battery of coke-ovens with by-product plant.

C. Jones (*Paper read before the National Association of Colliery Managers and the Association of Mining Electrical Engineers*, November 1916; *Iron and Coal Trades Review*, December 1916, vol. 93, pp. 721–724, 762–763) publishes some general notes on the electrical equipment of collieries.

Air Compressors.—An illustrated description is given (*Iron and Coal Trades Review*, October 1916, vol. 93, pp. 413–414) of the motor-driven air compressor recently installed at the Britannia Colliery of the Powell Duffryn Steam Coal Company, at Pengam, South Wales.

Mine Drainage.—The use of electrically driven pumps underground is discussed by H. S. Geismer (*Coal Age*, 1916, vol. 10, pp. 378–381), and the advantages of centrifugal and reciprocating pumps are described.

Methods of Working Coal.—P. Mullen (*Proceedings of the Engineers' Society of Western Pennsylvania*, 1916, vol. 32, pp. 714–721) describes a new method for mining bituminous coal as practised by the H. C. Frick Coke Company in the Connellsville region. It consists in the application of shortwall mining machines to the extraction of rib coal. The objects aimed at were to reduce the number of accidents and to obtain an increased output of coal per man per day. From the concentration made possible by this method, there has resulted a decrease in the cost of transportation, ventilations, track-work, and drainage due to the smaller area in operation

A description is given (*Iron and Coal Trades Review*, January 1917, vol. 94, p. 70) of the system of coal cutting and conveying adopted by the Stafford Coal and Iron Company at the Pender Colliery.

J. B. Warriner (*Bulletin of the American Institute of Mining Engineers*, No. 121, 1917, pp. 33–60) deals with the methods employed in anthracite stripping in the Pennsylvania coal region, and gives diagrams showing the methods of working.

Explosives.—An illustrated description is given of an apparatus for testing detonators and the relative efficiency of the different grades of commercial detonators. The method depends on the extent to which a clean dry sand of uniform granulation is pulverised by the explosion of the detonator charge (*Engineer*, October 13, 1916, vol. 122, p. 330).

Haulage in Coal-Mines.—R. Green (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, pp. 247–254) compares the costs of horse haulage with those of compressed air locomotive haulage. The comparison applies only to mines with seams 25° or more; pit cars containing 2 to 3 tons and grades from 0·46 to 1 per cent. in favour of

the loads, with roomy gangways and slight curves. The economic advantage passes from horse to compressed-air locomotive haulage somewhere between 25,000 and 30,000 ton miles monthly. The compressed-air haulage is about 3 cents per ton cheaper than horse haulage.

W. A. Machin (*Paper read before the National Association of Colliery Managers*, October 9, 1916; *Iron and Coal Trades Review*, November 1916, vol. 93, pp. 539–543) discusses the use of the jigging conveyor underground in conjunction with methods of working.

W. V. Johnston (*Iron Trade Review*, 1917, vol. 60, p. 53) has invented a new mine car, constructed of wood and corrugated iron strips, which it is claimed is not only strong and durable enough, but also has the elasticity which is so necessary in a mine car to allow it to resist severe service shocks.

Winding Ropes.—H. R. Smith (*Iron and Coal Trades Review*, March 1917, vol. 94, p. 361) gives some notes on winding ropes. The essential points to be considered in a winding rope are:

(1) Its life, (2) the factor of safety and the consequent breaking strain, (3) the size of pulleys and drums, (4) the speed of winding, acceleration, kinetic shock, and the resultant fatigue of the rope. No. 2 has, of course, an important bearing on 1, 3, and 4.

For engineers the following considerations are important: The type of the rope, governed by the size of the drum and pulley, the speed of winding and the acceleration; the breaking strain of the rope should be taken as a whole, and not as an aggregate of the wires; the actual number of torsions each wire will give in a standard engineering length of 8 inches; the actual number of bends of 180° which the wire will give over a standard radius before breaking; the fracture of the wire should be clean and free from defects of a structural nature.

Lighting of Collieries.—Some descriptive particulars and illustrations are given (*Iron and Coal Trades Review*, December 1916, vol. 93, p. 759) of several new safety-lamps recently approved by the Home Office for use in mines. These include the Kingsway electric safety-lamp, Davis-Edison accumulator electric safety-lamp, Cambrian Officials' lamp No. 7, Officials' pocket lamp, Best's gauzeless lamps, Nos. 1 and 1*a*, and the Ceag electric safety-lamp.

R. Nadin (*Paper read before the National Association of Colliery Managers* (Yorkshire Branch), December 1916; *Iron and Coal Trades Review*, December 1916, vol. 93, pp. 754–756) gives particulars of the cost and maintenance of an installation of electric safety-lamps of the Ceag type at Brierley Colliery, where 500 lamps have been in use since September 1913.

The Lambourne apparatus for relighting miners' lamps is illustrated and described (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 418). The invention consists of an improved form of magneto relighter.

W. Best (*Paper read before the National Association of Colliery Managers*, Scottish Branch; *Iron and Coal Trades Review*, November 1916, vol. 93, p. 637) gives an account of the construction of ancient and modern miners' safety-lamps. Reference is made to the inventions of De Humboldt, Dr. Clanny, George Stephenson, and Sir Humphry Davy.

Signalling in Collieries.—J. B. Thomson (*Transactions of the Institution of Mining Engineers*, 1917, vol. 53, pp. 51–57) gives a well-illustrated description of the "Chalmers-Black" non-accumulative visual indicator for shaft signalling. The apparatus is designed to meet the full requirements of the Coal Mines Regulation Act, and is especially suitable for shafts having intermediate loading stages.

D. M. Mowat (*Transactions of the Institution of Mining Engineers*, 1917, vol. 52, pp. 296–300) gives a description of the Summerlee visual indicator for signalling in winding shafts.

Gases in Mines.—G. A. Burrell, I. W. Robertson, and G. G. Oberfell (*U.S. Bureau of Mines*, Bulletin 105, 1916, pp. 1–88) report on the formation of black damp in mines, showing how atmospheric air, entering a coal-mine, loses oxygen and gains carbon dioxide, thus forming the so-called black damp. The effects of the constituents of black damp on men, on the burning of oil and acetylene lamps, and on the explosibility of methane are discussed.

The effects of temperature and pressure on the explosibility of methane-air mixtures have been studied by G. A. Burrell and I. W. Robertson (*U.S. Bureau of Mines*, Technical Paper 121, 1916, pp. 1–14). The results show that pressure and temperature conditions may vary over rather a wide range without affecting the explosibility of methane-air mixtures.

Coal-dust Explosions.—A. S. Blatchford (*Transactions of the North of England Institute of Mining and Mechanical Engineers*, 1916, vol. 46, pp. 235–251) gives the results of experiments on the influence of incombustible substances on coal-dust explosions.

Stone-dusting in Collieries.—A report of the discussion on the paper by G. D. Budge (*Read before the South Wales Institute of Engineers*, September 21, 1916) on stone-dusting in steam-coal collieries, has been published (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 578).

The plant for the production of stone dust at the Caerau Pit of North's Navigation Collieries, Ltd., is designed to produce 15 cwt. of finished dust per hour and requires about 28 horse-power to drive it. An illustrated description of the stone-crushing plant is given (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 489).

An illustrated description is given (*Iron and Coal Trades Review*, December 1916, vol. 93, p. 757) of the Kek mill for grinding stone dust,

manufactured by the Chemical Engineering Company, Deansgate, Manchester. The machine occupied a floor space of 54 inches, by 40 inches by 38 inches. The size of the grinding discs was 26 inches, and the output of the machine was approximately 20 cwt. per hour, the machine taking 20 to 25 horse-power to drive it.

Rescue Operations.—J. W. Paul and H. M. Wolflin (*U.S. Bureau of Mines*, 1916, 16mo pamphlet, pp. 1–109) have prepared a publication containing suggestions and advice regarding mine rescue and recovery operations after explosions and mine fires. The organisation of rescue work and the procedure to be followed are fully dealt with.

Coal Storage.—A large under-water coal storage is being constructed adjoining the main power plant of the Duquesne Light Company on Brunots Island in the Ohio river just outside Pittsburgh (*Iron and Coal Trades Review*, January 1917, vol. 94, p. 30). It will have a capacity of 100,000 tons of bituminous coal and equipment for rapidly loading and unloading. The design consists of an excavation 800 feet long, 173 feet wide, and 25½ feet in depth, lined with concrete, the bottom being composed of concrete slabs 50 feet square and 15 inches thick. The bottom of this storage pit, which is to be made wholly water-tight, is on a level with the "pool stage" of the Ohio river at this point—that is, it has been built so that in all normal times the pit will be even with the water line of the river.

Sanitation in Mines.—The report of the Committee on Safety and Sanitation in Mines, appointed by the American Institute of Mining Engineers (*Bulletin of the American Institute of Mining Engineers*, 1917, No. 121, pp. 88–122) has been presented. It contains a classified synopsis of the data collected during the inquiry, and a number of pattern rules in force at various mines and collieries are co-ordinated into a systematic code of regulations intended to promote the objects for which the committee was originally appointed.

The precautions to be employed in shot-firing are discussed by M. D. Cooper (*Ibid.*, pp. 123–133).

Valuation of Coal-Mines.—R. V. Norris (*Transactions of the International Engineering Congress; Mining Engineering*, San Francisco, 1915, pp. 135–149) deals with the valuation of anthracite mines on the basis of royalties, tonnage, probable profits, mining costs, future production, and improvements.

VIII.—*HANDLING AND PREPARATION OF COAL.*

Coal-Handling.—J. P. Griffith (*Minutes of Proceedings of the Institution of Civil Engineers*, 1915–16, vol. 202, pp. 328–333) reviews the progress in the development of coal-handling machinery, and reference

is made to a number of modern coal-handling installations at British ports.

H. Goldstein (*Iron Trade Review*, 1917, vol. 60, pp. 193–195) gives an illustrated account of a method of handling coal in storage plants.

J. E. Lister (*Transactions of the Society of Engineers*, 1916, pp. 65–88) gives an illustrated description of modern coal- and coke-handling machinery.

Briquetting Coals.—F. C. A. Lantsberry and J. D. Paton (*Paper read before the Manchester Geological and Mining Society*, December 1916; *Iron and Coal Trades Review*, December 1916, vol. 93, p. 765) discuss the question of fuel economy, with special reference to the briquetting of coal. The requirements of good briquettes for fuel are enumerated, pitch being recommended as the best binding material.

For successful briquetting it is essential to use a pitch that softens between 40° and 70° C. and yields a hard sintered residue on coking. About 70 per cent. of this residue should be extracted by the use of carbon disulphide; its hydrogen content should not exceed 5 per cent., and its calorific value should be not less than 8500 calories. Experience in Germany indicates that blast-furnace pitch is not suitable as a binding material, as this material always gives a puffed residue on coking. The amount of pitch necessary to effect a proper adhesion of the particles of coal in the finished briquette varies between 7 and 10 per cent. of the mixture.

S. M. Darling (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, pp. 222–225) describes the carbonising and briquetting of Saskatchewan lignites. Dried lignite, mixed with 6 to 7 per cent. of coal tar or petroleum pitch and 7 to 8 per cent. of coking coal, makes a briquette which in tests has proved equal to Alberta coals.

C. E. Lesher (*U.S. Geological Survey, Mineral Resources*, 1915, Part II. 1, pp. 1–6) reports on the fuel briquetting industry of the United States. The production of briquetted fuel in 1915 was 221,537 short tons. The number of plants in operation was fifteen, of which five used coal-tar pitch as a binder; two used tar mixed with other substances; three used asphaltic pitch; one used an organic binder; and one used petrolastic cement. No binder is required in briquetting carbon residues from oil-gas works or at the lignite plant in California.

An illustrated description is given (*Iron and Coal Trades Review*, February 1917, vol. 94, pp. 147–148) of the briquetting plant at the Clifton Collieries, Notts, for the treatment of coal less than quarter-inch.

Charcoal Briquetting.—An illustrated description is given of a machine for briquetting charcoal made by Messrs. Bradley & Craven (*Iron and Coal Trades Review*, March 1917, vol. 94, p. 361). Charcoal and pitch are used for feeding, and the machine is capable of briquetting 15 to 20 tons in ten hours.

PRODUCTION OF IRON.

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I.—*BLAST-FURNACE PRACTICE.*

Blast-Furnace Operations.—J. E. Johnson, Jun. (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 235–244) discusses blast-furnace operations from the commercial point of view. The aspects dealt with are the location and construction of the plant; the construction of cost sheets; the choice of the most economical size and rate of driving for furnaces, and their effect on profits; the utilisation of the by-products, including the slag, and gases; the limitations attainable in fuel economy; and the use of the dry-air blast.

J. E. Johnson, Jun. (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 17–20) discusses the future of the pig-iron industry and the directions in which changes in blast-furnace practice may be conceived of as likely to take place. The possible exhaustion of ore supplies is dismissed as a mere scare, as the lower grades occur in almost unlimited amounts, and as the percentage of iron in any given rock falls, the supply of such rock or "ore" increases out of all proportion to the decrease in iron content. It remains for the metallurgy of the future to render these supplies economically available, and while the cost of pig iron might increase, this will be offset by other considerations, notably the increased value of the by-products, by which are meant not those alone that are already known and used, but those incidental to future changes in blast-furnace practice. Amongst the latter is the possibility of using an enriched, or even all-oxygen blast. This would be accompanied by the use of the separated nitrogen of the air for "fixation" purposes. The uses of the slag are by no means exhausted. More slag would be made in such conditions. The use of oxygen would reduce the fuel consumption by, it may be estimated, as much as two-thirds. A proposed design of furnace with modified top, to be used with oxygenised blast, is shown as a suggestion of possibilities yet to be realised.

How tuyeres indicate furnace conditions is the subject of a short note by W. G. Imhoff (*Blast-Furnace and Steel Plant*, July 1916, pp. 326–328).

Balance of the Blast-Furnace.—B. Neumann (*Metallurgia Italiana*, April 1916, vol. 8, pp. 248–259) gives elaborate data concerning the balance of materials charged and the product, and the heat balance of electric furnaces for smelting iron ore.

Manufacture of High Manganese Iron.—W. G. Imhoff (*Blast-Furnace and Steel Plant*, January 1916, pp. 13–14), in discussing the uses of extra coke in the blast-furnace, mentions that one of the most important is in making high manganese iron. To make such iron, remove all the lime possible and still hold the sulphur where desired. As the lime is removed put in extra coke. Also remove all sulphur-bearing ores from the burden and prevent as far as possible sulphur going into the blast-furnace. The condition of the carbon is of extreme importance. It must be in the combined form and the furnace must be hot. With minimum lime a lime silicate slag forms which with extra coke gives maximum combined carbon iron, which in turn will absorb the largest amount of manganese.

Coke Consumption in Blast-Furnaces.—H. P. Howland (*Blast-Furnace and Steel Plant*, May 1916, pp. 219–230 and 240) deals with the question of economy in the use of blast-furnace carbon, endeavouring in particular to solve the problem as to why one coke is better than another. The difference is not due to a difference in the carbon in the coke, nor to difference of quantity of blast required per pound of coke. The most desirable quality in coke is that the carbon should be of a character which will allow of its being instantaneously burned to CO at the tuyeres, giving the maximum concentration of heat where needed. A large number of calculations are given in connection with the question.

Use of Carbon in Blast-furnace Practice.—W. Mathesius (*Bulletin of the American Institute of Mining Engineers*, No. 125, 1917, pp. 834–854) criticises at length the conclusions reached by Howland. He traverses the figures quoted and arrives at 0·68 kilogramme of carbon oxidised per kilogramme of pig iron made, as against 0·66, the amount given by Howland. He further calculates that 9·2 of the iron charge is reduced in the hearth and 90·8 per cent. in the shaft. Of the latter 15·8 is also "direct reduction," leaving 75 per cent. indirect reduction in the shaft, by carbon monoxide, and a total of 25 per cent. direct reduction. This result he then compares with ordinary practice. In foundry iron furnaces three-fourths of the direct reduction takes place in the shaft and one-fourth in the hearth, while in basic pig-iron furnaces about 70 per cent. of the direct reduction takes place in the hearth and

30 per cent. in the shaft. This is due to the shaft being hotter than in furnaces making foundry iron. If the blast temperature were raised to 800° C. no advantage would accrue on the same ore being used. A more refractory ore could, however, be employed as efficiently as one more easily reduced. Copious calculations are given and the heat balances worked out in great detail.

Use of Pulverised Coal as Fuel in the Blast-Furnace.—Sections are shown of the injector and tuyere nozzle for blowing powdered coal into the blast-furnace if a higher temperature is required for the manufacture of special irons or for restoring normal temperature in the hearth. Very little change in the equipment is required, and a high heat can be obtained with a corresponding reduction in coke consumption (*Blast-Furnace and Steel Plant*, July 1916, pp. 315–316).

Pyrites Cinder in Blast-Furnaces.—W. W. Taylor (*Iron Trade Review*, 1917, vol. 60, pp. 581–582) gives some observations on the manner in which pyrites cinder behaves in a blast-furnace especially designed for the purpose.

Distribution of Charge in Blast-Furnaces.—A. C. Nelson (*Iron Trade Review*, 1917, vol. 60, p. 154) has patented a mechanism for effecting better distribution of ore, coke, and limestone in blast-furnaces. The distribution is accomplished by means of blades. The device is used in connection with the customary equipment of furnace bell, main hopper, receiving hopper, skip, and upper bell. The stock dumped from the skip passes through the receiving hopper and the cylinder, and is divided by the distributing blades into as many paths as there are blades. The charge will thus be deposited at the same number of points in the main hopper as there are blades. By rotating the distributor, the next charge may be dumped between the points where the preceding one was deposited. After observing the amount of rotation necessary for the best distribution, the rotating mechanism may be adjusted to operate automatically. The author claims that his invention permits an improved control over the distribution of stock in the main hopper, and thus in the furnace. The importance of proper control over the distribution of the stock is clearly understood. The charge being of different grades of coarseness, the most satisfactory distribution is found when the lumps are in the centre of the furnace and the fines next to the walls. This arrangement permits an unobstructed draft and prevents uneven wear on the furnace lining.

K. L. Landgrebe (*Blast-Furnace and Steel Plant*, July 1916, pp. 329–330 *et seq.*) gives a description of the Brown furnace-top, in which various modifications are introduced to adapt it to local conditions, at the Ensley blast-furnaces, and by means of which a great improvement in the distribution in the furnace was obtained.

Hot-Blast Stoves.—A. J. Boynton (*Paper read before the St. Louis Meeting of the American Iron and Steel Institute; Iron Age*, 1917, vol. 99, pp. 202–205, and 254–258) discusses recent progress in the design of hot-blast stoves and the problems of brick sizes, shape and spacing; the combustion chambers, the blast temperatures, and the relative advantages of two, three, and four pass stoves. Since the transfer of heat takes place by conduction, and since the conductivity of firebrick is low, it is of primary importance to place the average mass of the firebrick as close to the heating surface as possible, which means that the checker work should be as thin as structural strength will permit. All available data show that a given heating surface is best arranged both for heat and for economy when grouped in the fewest practicable units of large size. The present tendency is to provide three stoves per furnace.

Turbo-Blowers.—Particulars and illustrations are given (*Iron and Coal Trades Review*, January 1917, vol. 94, pp. 1–3) of the blowing and power plant installed by the Millom and Askam Hæmatite Iron Company at their Millom works. The plant consists of five Fraser and Chalmers high-pressure steam turbines, of which two are used for generating electricity and three for driving turbo-blowers. Each of the turbo-blower sets is capable of delivering 30,000 cubic feet per minute at 8 lb. pressure when running at 2800 revolutions per minute, at which speed the turbines develop 1280 brake-horse-power with a steam consumption of 13·9 lb. per brake-horse-power.

The blowing plant installed by the Barrow Hæmatite Steel Company at their Barrow-in-Furness works is described (*Iron and Coal Trades Review*, January 1917, vol. 94, pp. 96–97). It is the first plant capable of supplying blast to the Bessemer converters and the blast-furnaces. The scheme adopted provides for mixed pressure turbines to drive a combination of turbine blower and turbine compressor. When used for blowing the Bessemer converters, the blower is run as a two-stage compressor and delivers the air at a pressure of 30 lb. per square inch, whilst for blowing the blast-furnaces the two stages are run in parallel, each delivering air into a common main at 12 lb. pressure.

Turbo-Blower Regulators.—R. H. Rice and S. A. Moss (*Proceedings of the Engineers' Society of Western Pennsylvania*, 1917, vol. 33, pp. 81–115) consider that the turbo-blower for the blast-furnace is a most important factor for securing proper working of the furnace. As a means for regulating the rate of flow of blast a constant-volume governor has been introduced, including a device called a volume corrector by which the effects of changes of barometer, thermometer, and humidity are readily corrected

C. Grosswendt (*Blast-Furnace and Steel Plant*, September 1916, pp. 426–428) supplements the foregoing article with a number of cases to which turbo-blowers and compressors are applicable. The various means for providing for speed regulation are considered.

Gas Cleaning.—Dry hot *versus* cold wet methods of cleaning blast-furnace gas are discussed by L. Bradley, H. D. Egbert, and W. W. Strong (*Bulletin of the American Institute of Mining Engineers*, No. 122, 1917, pp. 209–224). The conclusions arrived at are summarised as follows: (1) Generally speaking, the sensible heat energy of the top gas from a blast-furnace is much greater than that of the moisture carried away from the stoves, hence a hot dry method conserves the sensible heat energy better than a cold wet method. (2) It also allows of a higher flame temperature being obtained and recovers the fume and dust in a more saleable condition. A great saving is also effected by the use of a dry hot method, and in this connection the electrical method is unique and specially well adapted to fine ores, while it also prevents troubles from slow ignition and imperfect combustion. Finally dry methods admit of a far better recovery of valuable volatile constituents.

A. F. Nesbit (*Blast-Furnace and Steel Plant,* April 1916, pp. 160–161) describes a method for the precipitation of flue-dust from blast-furnace gas by electrical means.

C. C. Lynde (*Blast-Furnace and Steel Plant*, October 1916, pp. 462–466) reviews the economies effected by washing blast-furnace gases. The general arrangement of the Brassert-Bacon washing and drying system is shown, with a description of the plant and its mode of operation. The immediate economies secured by washing all the gas are the saving in the cost of operation, upkeep, and relining the stoves; the saving in coke consumption; the saving in operation and repairs of boilers; and through greater economy in stoves and boilers there is a larger surplus of gas available.

Burners for Blast-Furnace Gas.—C. C. Lynde (*Blast-Furnace and Steel Plant*, August 1916, pp. 365–367) illustrates and describes various types of burners for the burning of blast-furnace gas in stoves and under boilers. Sight pieces at the back of the burner are provided to enable the combustion to be observed and regulated.

A description is given of the Mackinlay gas burner for firing blast-furnace gas under boilers (*Iron and Coal Trades Review*, January 1917, vol. 94, p. 69). The apparatus consists of a special furnace front through which two pipes in parallel are passed; they are attached to the junction-box on the furnace front and led to a point near the end of the combustion chamber, where they are connected by means of a Y bend to the return pipe, which is equal in diameter to the two pipes. The gas main is connected to the top of the junction-box. By this means the gas is preheated before burning under the boilers.

To start up the boiler a shovel of hot coal is placed under the return pipe and gas turned on. Once the gas is lighted no further attention is required; the flame then playing around the two leading pipes preheats the gas on its passage to the burner. Since the installation

of the apparatus no trouble has been experienced with the gas going out, and obviously there is no cinder bottom in the grate.

Some interesting results of tests made on the same gas-fired boiler, without and with the preheater burner, are given.

Equipment of Blast-Furnaces.—A description is given of lifting magnets installed for the purpose of handling material in stockyards (*Electrician*, March 1917, vol. 78, p. 717).

Safety Precautions at Blast-Furnaces.—F. H. Willcox (*U.S. Bureau of Mines*, Technical Paper 136, 1916, pp. 1–73) reports on the measures to be taken to minimise the risk of accidents at blast-furnaces. Precautions to be observed and the means for putting recommendations into effect are considered, and some notes on first aid are given.

Electric Smelting of Manganese and Chromium Ores in California.—The Noble Electric Steel Company of San Francisco has worked continuously its electric smelting plant at Heroult since April 1916, turning out a ferro-manganese product (*Iron and Coal Trades Review*, January 1917, vol. 94, p. 39). The furnace now in use is described as the Frickey open-delta, split-phase arrangement of electrodes, and it is considered successful with ferro-manganese ores, the smelting of which was begun in 1914. The closing down at intervals is said to have been due to a shortage of ore. The ore smelted varies, but much of it runs 46 to 48 per cent. metallic manganese, 14 to 16 per cent. silica, and 2 to 3 per cent. iron. The furnace product contains 80·5 to 81·5 per cent. manganese. The plant capacity is 9 tons per day, but is to be increased. The same company, in 1915, began developing and mining chromite ore on a number of properties in California. Part of the ore is shipped east, and a part is smelted at the Heroult plant by methods practically similar to those employed in ferro-manganese smelting. The analysis of average ore shows 30 per cent. chromic oxide, and 13 per cent. ferrous oxide. The furnace product is a ferro-chromium.

Smelting of New Zealand Ironsands.—According to H.M. Trade Commissioner in New Zealand (*Mechanical Engineer*, 1917, vol. 39, p. 145) a company has recently been formed in New Zealand with a capital of £70,000 with the object of producing iron and steel from magnetic and titaniferous ironsands, of which there is a large deposit on the coast of Taranaki, near New Plymouth, North Island. Works are being erected at New Plymouth. The present intention is to instal a furnace capable of dealing with 70 tons of ironsands weekly, but plans have been drawn up for the installation at a later date of an additional furnace, capable of dealing with 200 tons of ironsands weekly. The company claims that as a result of experiments, and from actual practice, pig iron can be produced from ironsands at a cost not exceeding

£3 a ton. The production of steel is also contemplated, and it is intended later to form a new company to carry out this development. Meanwhile the company will proceed with the production of pig iron for foundry purposes.

Potash from the Blast-Furnace.—R. J. Wysor (*Bulletin of the American Institute of Mining Engineers*, No. 121, 1917, pp. 1–32) describes his investigations on the recovery of potash from the blast-furnace. The experiments were chiefly carried out at the furnaces of the Bethlehem Steel Company, South Bethlehem, Pennsylvania, where, some years ago, an analysis was made of the fine, yellowish fume of which a considerable quantity was removed from the bottom of the stove checker work. This was in the course of investigating blast-furnace stove efficiencies. The sample was found to contain about 15 per cent. water-soluble potash, which was somewhat surprising. This induced an investigation which showed that considerable quantities of this material, hitherto a waste product, could be recovered from the stoves and gas-fired boiler settings.

A search for a market was made without immediate satisfactory results, one fertiliser dealer claiming that the alumina content was too high. Others wished to make practical tests, and they were furnished with large samples for a full season's demonstration, satisfactory results being reported. But the pre-war-time prices offered hardly seem to justify reclaiming the dust. After the war started, however, and after the spectacular rise in the potash market, reclamation was immediately commenced, knowing just what dust to recover, and a satisfactory contract was negotiated. This company has been disposing of the dust at a good profit ever since.

Potash enters largely into the composition of nearly all the constituents of the charge, and analyses of the ores, fuels, and fluxes used are given showing the extent per cent. to which alkalies are present. Probably much of the potash and soda charged into a blast-furnace is evolved from the top by direct volatilisation or heat decomposition, though alteration by chemical reaction of the alkaline salts or compounds liberated may occur before they have left the furnace. It is certain that a large part of the alkalies is carried down into the hotter zones of the furnace and is converted into cyanides by reaction with red-hot carbon. Some investigators have attributed an appreciable part of their ore reduction to the action of cyanides, inferring that after being oxidised and driven to the cooler upper portion of the furnace, they condense and are again carried down into the reducing zone. Whatever the action it is self-evident that eventually the same amount of alkalies must be carried out of a furnace that is charged, and this takes place through the following avenues of escape: 1. In chemical combination in the slag. 2. As cyanide or other volatile or inflammable compound through the iron and cinder notches. 3. By liquid exudation or decomposition from gas around the tuyeres, coolers, mantel and

cooling plates. 4. By combination with the brickwork or as an accretion in the form of cyanide, &c., and removal when the furnace is blown out. 5. By evolution in the gas.

In the gas-cleaning practice now in vogue at South Bethlehem there is a total loss in the primary washers of over half the total potash charged, or about 12 lb. per ton of pig iron produced. The amount recovered, while appreciable, and representing almost clear profit, is seen to be an insignificant part of the total, less than ½ per cent. The potash lost in the slag, around the shell and from the top of the furnace, for all practical purposes, is lost beyond recovery. The greater part of the alkali content of the flue-dust removed from the dust-catchers could be recovered by leaching in water, but the percentage is too low to justify reclamation in this way. However, the potash now lost in wet washers and from stove and boiler-house stacks offers a legitimate and inviting field for its recovery. According to a balance sheet, it appears that about two-thirds of the total potash charged is now lost in the wash water and stack gases, or about 15 lb. per ton of pig iron produced.

The commercial aspect is not dealt with, but enough evidence is adduced to show that the recovery of potash from blast-furnace gas presents highly attractive possibilities. A bibliography of the subject is appended.

C. Catlett, in discussing the subject dealt with by R. J. Wysor (*Ibid.*, Bulletin No. 125, 1917, pp. 831–833), points out that many iron ores are higher in potash than those instanced, and that the extraction of potash is a consideration that should be taken into account in the selection of ores. The blast-furnace practice of the future will probably develop recovery processes from this point of view.

Amongst the sources of potash noted by F. M. de Beers (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 508–510) in a review of the potash industry of the United States, is blast-furnace gas, which is stated to be a prolific source of the alkali.

H. A. Huston (*Ibid.*, p. 615) challenges some of the figures quoted by de Beers, who replies explaining the alleged discrepancies which do not, he claims, vitiate the conclusions.

Blast-Furnaces in France.—It is reported by the British Consul at Havre (*Journal of Industrial and Engineering Chemistry*, January 1917, vol. 9, p. 319) that the iron-mines and blast-furnaces of Caen are at present being worked by the Government, and that the industry, which was languishing for many years, is now in a most flourishing condition. A large new plant of the most modern type is being installed, and the railway authorities are doing their utmost to develop the industry. The output of iron ore in the district has now reached over 1,000,000 metric tons per annum.

Classification of Pig Irons.—J. Johnson, Jun. (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 324–328) divides the classes

of pig iron made in the blast-furnaces into four main groups, steel-making irons, foundry irons, puddling irons, and ferro-alloys, and describes their chief characters and the limits of their composition. The special requirements of the Bessemer converter and of the duplex systems of steel-making are separately considered.

W. G. Imhoff (*Blast-Furnace and Steel Plant*, January 1917, pp. 9–11) considers practical methods of judging the analysis of pig iron at the time of tapping and the causes which give individuality to the appearance of each test sample notwithstanding similarity of composition.

History of Iron; Joseph Hall, Memoir of.—J. W. Hall (*Paper read before the Staffordshire Iron and Steel Institute*, March 1917) has published a memoir of Joseph Hall, the inventor of the modern system of puddling, with an account of his experiments and the establishment and rise of the firm of Bradley, Barrons, & Hall, for many years manufacturers of the "Crown BBH" brand of wrought iron.

II.—*BLAST-FURNACE SLAGS.*

Measurement of Viscosity of Blast-Furnace Slag at High Temperatures.—A. L. Feild (*U.S. Bureau of Mines*, Technical Paper 157, 1916, pp. 1–29) has investigated the problem of slag viscosity, its variation with the temperature and composition of the slag, and its effect upon the distribution of the sulphur between molten iron and slag. The author uses a modification of the method originated by Margules (*Sitzungsberichte d. Akademie für Wissenschaft*, Vienna, 1881, vol. 83, Part II., p. 588) for the measurement of viscosity, and the apparatus and experimental operation are described in detail. Viscosity and fluidity curves are given for eight typical slags. The average viscosity at 1500° C. of the eight slags was found to be 301 (H_2O at 20° C. = 1), corresponding to a viscosity less than that of castor oil at room temperature, but greater than that of olive oil. A refractory slag possessing a high initial softening temperature is not necessarily more viscous at high temperatures than a more fusible slag. This fact was shown by experiments with a slag containing 35·3 per cent. of alumina.

A. L. Feild (*Bulletin of the American Institute of Mining Engineers*, No. 122, 1917, pp. 307–332) deals further with the viscosity of blast-furnace slags. The temperature-viscosity curve generally approximates in form to a rectangular hyperbola, whereas the temperature-fluidity curve approaches a straight line. The differences between softening temperature, determined by the deformation test, the physical melting point of slags and their viscosity, are discussed, as well as the nature of the free running temperature of slags and the measurement of slag temperatures at the furnace.

Iron in Blast-Furnace Slag.—W. G. Imhoff (*Blast-Furnace and Steel Plant*, August 1916, pp. 359–361) considers the causes and conditions of iron in slags, its physical and chemical states, and its relation to the furnace working.

Slag Breakers.—H. V. Schiefer (*Blast-Furnace and Steel Plant*, November 1916, pp. 499–502) describes appliances for breaking up, screening, and preparing slag for ballast and road material.

Slag-Handling.—C. C. Lynde (*Blast-Furnace and Steel Plant*, January 1916, vol. 50, pp. 1–4) describes two methods for the recovery of slag and cinder at blast-furnaces in a condition to be utilised for road-making, cement manufacture, and other industrial uses.

III.—*DIRECT PROCESSES AND PUDDLING.*

History of Puddling Process.—D. F. Manice (*Blast-Furnace and Steel Plant*, February 1916, pp. 82–84) gives a brief historical review of the manufacture of wrought iron, describing the operations carried out in the puddling process.

C. H. Desch has prepared a preliminary report for the British Ironmasters' Puddling Research Committee (1917). The report consists of a history of improvements in the puddling process.

FOUNDRY PRACTICE.

General Foundry Practice.—A. E. Howell (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916), who has had thirty-five years' experience in foundry work largely devoted to the manufacture of light castings, compares the conditions of the foundry industry in the early eighties with those prevailing to-day. The wonderful progress that has been made is recorded, and attention is directed to some of the notable advances, such as the Keep shrinkage test and the development of the aluminium match-plate. The operation of the cupola is discussed briefly, and the question of slagging is considered.

D. W. Sowers, J. H. Hall, and others (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) point out the necessity for closer co-operation between the engineer and the foundry. Numerous actual instances of effective co-operation are cited in which effort and money were saved by working together. The necessity for suitable standard specifications which will be thoroughly understood by all concerned is discussed. It is also pointed out that the various materials used by the foundryman for making castings, such as grey iron, steel, malleable iron, brass, aluminium, &c. each have peculiar physical characteristics which should be considered by the engineer in designing parts. On the other hand, foundrymen should also constantly strive to improve the quality of their castings in order to provide the engineer with the most satisfactory material.

E. Adamson (*Paper read before the Scottish Branch of the British Foundrymen's Association; Foundry Trade Journal*, 1917, vol. 19, pp. 73–79, 140–144) has written an exhaustive article on cast iron.

J. Grennan (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) gives an account of a course of foundry work at the University of Nebraska.

Air Supply for Cupolas.—J. A. Shorey, at a meeting of the Newark Foundrymen's Association (U.S.A.), discussed the relation of air supply to cupola blowing (*Foundry Trade Journal*, September 1916, vol. 18, p. 473). He said that it had generally been accepted that 30,000 cubic feet of displaced air should be allowed for each ton of iron under ordinary conditions of melting. From computation, it has been assumed that 150 cubic feet of air are required to burn 1 lb. of carbon to carbon dioxide, and in ordinary practice 1 lb. of coke is sufficient to melt 10 lb. of iron. This assumption is made on the basis that

coke is pure carbon. Commercial coke analyses vary widely, but a fair average of carbon may be assumed to lie between 85 and 90 per cent., which reduces the air requirement in this proportion. In actual practice 24,000 cubic feet of free air has been found necessary for the melting of 1 ton of iron under the assumed ratio of 10 to 1. The oxygen content by weight of a cubic foot of air varies directly as the barometric or absolute pressure. Tests have indicated a variable ranging from 5 to 10 per cent. of the total iron melted. In other words, in operating a cupola, while the coke is carefully weighed, likewise the iron, the weight of the air and rate at which it is supplied, which are of equal importance, are left to the judgment of the operator, or to the exigencies of handling the iron, rather than to the over-all economy of melting.

Use of By-Product Coke in Foundries.—G. A. T. Long (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916), after outlining the requisites of a good by-product foundry coke, proceeds to discuss the use of this fuel in cupolas. For ordinary soft grey iron castings the bed should be brought up to 24 inches above the tuyeres. The charge put on the bed should be used all through the heat. Small charges also are recommended. In ordinary cupolas 24 to 36 inches inside diameter, 1000-lb. charges are considered satisfactory. In cupolas from 36 to 54 inches, 2000-lb. charges are preferred. In larger cupolas 3000 lb. is considered the limit. The blast-pressure should be kept as low as possible in order to avoid trouble from slag, hard iron, shrinkage, &c. It is not believed necessary to select large-sized coke for the bed, inasmuch as the large pieces leave too much space for the passage of air. Continuous melting is simply a question of how long the lining will last.

Use of Pressed Cast Iron Turnings in the Cupola.—R. Fichtner (*Stahl und Eisen*, 1916, vol. 36, pp. 77–86, 181–190, 311–318, 411–416, 507–516; *Iron and Coal Trades Review*, 1916, vol. 93, p. 415) considers the use of iron and steel briquettes in cupola melting.

Well-pressed briquettes of cast-iron turnings (of a weight of from 10 to 12 kilogrammes) have a specific gravity up to 5·8, whereas cast iron has one of 7·2. If this density is represented by 100 the cast-iron briquettes show an 80 per cent. compression. The specific gravity of steel-turnings briquettes is 5 to 5·2, and that of wrought iron or steel 7·8, the compression in the case of the steel briquette consequently being 66 per cent.

Experiments undertaken with well-pressed briquettes of cast-iron turnings show that they can be advantageously remelted in cupolas. If briquettes only were remelted the waste considerably increased on a simultaneous slagging of the furnace; but no great waste occurred when the operation was conducted with pig iron and scrap with up to 30 per cent. of briquettes. Experiments made in 1910 indicated how

the strength increased with the increasing use of briquettes in the charge. In a mixture of hæmatite and briquettes of cast-iron turnings the briquette content was raised from 20 to 90 per cent.; and a constant increase took place in the tensile and transverse strength. But with the larger addition of briquettes (80 to 90 per cent.) the iron began to be brittle and its strength to decline. One disadvantage always observed was a higher absorption of sulphur in the iron, according to the increase in the percentage of briquettes.

During 1915 Wüst carried out experiments in the foundry of Sulzer Brothers at Winterthur. Charges were employed consisting of hæmatite and Luxemburg iron, together with an admixture of briquettes formed of cast-iron turnings in proportions rising from 5 up to 25 per cent., so that the composition of the charge in carbon, silicon, manganese, phosphorus, and sulphur remained approximately the same. The experiments resulted in an increase in the transverse strength with test-bars up to 35 per cent. and in the tensile strength up to 50 per cent. It has been established that: (1) The total waste increases proportionately to the addition of briquettes; (2) that the carbon loss does not materially increase; (3) that the proportionate loss in silicon increases with an increasing use of briquettes; and (4) that an increased absorption of sulphur through the briquettes does not occur.

J. A. Murphy (*Paper read before the American Foundrymen's Association, Cleveland,* September 1916) deals with the use of borings in cupola operations. For many years iron borings and steel chips have been charged in cupolas to reduce the cost of the mixture and to better the quality of the metal. When borings or chips have been charged loose with pig iron and scrap the melting loss is excessive, and when charged alone the heat does not penetrate the mass far enough to melt the entire charge. The practice of laying a bed of borings on the cupola bottom is unsatisfactory because heat is wasted. Stanton Griffith accidentally discovered that by using lengths of stove pipe as containers, chips and borings could be charged in the cupola in such a way that the melting loss amounted to only 2 per cent. The stovepipe cartridges hold about 50 lb. of borings, and the cost of preparing them does not exceed $2.50 per ton. In 1908 Walter F. Prince introduced a method of melting chips in a vertical tube placed in one side of the cupola. Although satisfactory in many respects, this process lacks the simplicity which marks the cartridge method, and is less economical. The briquetting of borings by means of great pressure gives satisfactory results, but the cost of preparing the briquettes is high. Briquettes in which binders are used produce castings containing pinholes and blowholes, and the melting loss in the cupola amounts sometimes to 60 per cent. Castings made from similar metal which had been charged with borings in cartridges are sound in every respect.

Use of Grey-Iron Scrap in the Cupola.—In a paper on "The Use of

Cheaper Materials," read by C. C. Kawin before the American Foundrymen's Association (*Foundry Trade Journal*, November 1916, pp. 602–603) the author discusses the economies that may be realised from the use of liberal proportions of stove plate and other scrap in grey-iron foundry mixtures. He points out that silicon is one of the principal elements in a cupola mixture, and demonstrates that the proper proportions of silicon for various classes of castings can be secured when using large amounts of scrap, provided the output is watched carefully and analyses are made regularly. Tables are appended giving details of three all-scrap mixtures and one 75 per cent. scrap mixture that are said to have been used successfully, viz.: (1) All-scrap mixture containing stove-plate and agricultural scrap (2 per cent. silicon in castings); (2) mixture containing malleable and steel scrap (1·50 per cent. silicon in castings); (3) mixture containing machinery scrap with malleable and steel scrap (1·00 per cent. silicon in castings); (4) mixture containing 75 per cent. scrap and 25 per cent. pig (2·00 per cent. silicon in castings). Since an iron showing 0·70 per cent. silicon, 0·50 per cent. manganese, 0·325 per cent. phosphorus, 0·150 to 0·200 per cent. sulphur, and 3·40 per cent. carbon, when poured into a 1-inch square test-bar, drills very easily with a $\frac{5}{8}$-inch drill, and as these mixtures are higher in silicon and lower in sulphur, they should be sufficiently soft for castings of 1 inch or more in thickness.

Properties of Foundry Iron.—J. E. Johnson, Jun. (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 530-537 *et seq.*) discusses the chemical and physical properties of foundry iron. Oxygen is shown to have a great influence on the strength, closeness of grain, and wearing qualities of cast iron. Recommendations as to the proportion of constituents in cast iron, suitable for castings for special purposes, are given.

The chemical and physical properties of foundry irons are discussed by J. E. Johnson, Jun. (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 530–537, and 589–597), who gives diagrams and photomicrographs illustrative of the principle points dealt with, which comprise chemical composition, the iron-carbon diagram as it applies to cast iron, the condition of the carbon, including the shape and form of the graphite crystals, the eutectic ratios, and the influence of elements other than carbon. The latter part of the subject is dealt with in considerable detail under the headings silicon, sulphur, phosphorus, oxygen, and manganese.

Cleaning Waste Foundry Sand.—H. B. Swan and H. M. Lane (*Paper read before the American Foundrymen's Association*, September 1916) deal with the subject of waste foundry sand. In collecting data for their paper the authors sent a list of ten questions dealing with the sand-disposal problem to a large number of representative foundries.

The replies received indicated that there is a lively interest in the waste-sand question among progressive foundry managers, although in most cases at present no practical reclamation methods have been devised. One foundry reported, however, that it was possible, at a very nominal expense, to take refuse sand and convert it back to a condition fit for use. In fact it was almost impossible to tell the old from the new. The authors point out that what is wanted is a process that will clean the largest amount of sand at the least expense. For instance, a process that recovers 80 per cent. of the sand in a fairly usable condition may be better than one that recovers 90 per cent. in a better condition, but at a higher cost.

A description is given of an installation for reclaiming waste moulding sand. The apparatus was supplied by the Modern Foundry Company, Oakley, Cincinnati. The material reclaimed in six weeks is said to have paid the original cost of the equipment (*Iron Age*, 1916, vol. 98, p. 505).

Patterns.—W. W. Carlson (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) suggests a standard for pattern parts.

Metal-Coating Wood Patterns.—In a paper read before the American Foundrymen's Association E. A. Barnes (*Foundry Trade Journal*, December 1916, vol. 18, p. 643) discusses the use of metal-coatings for wood patterns.

Drawings for the Pattern Shop.—L. F. Neminger (*American Machinist*, vol. 46, p. 138) gives a quick method for making drawings for the pattern shop. In some drawing offices detail drawings are dimensioned only in places where parts are to be machined. Casting sizes are omitted, so as not to confuse the men in the shop in their work with these drawings. To furnish the pattern shop with a suitable drawing giving all pattern dimensions usually requires the making of a complete separate drawing. A convenient and time-saving method to produce a pattern drawing is to take the detail drawing and pin down a piece of tracing cloth over it. Trace on all the dimensions necessary for the pattern shop. It is not necessary to trace the outlines or other dimensions already given on the detail drawing. Carefully mark the two tracings with a cross, so that when pattern blue prints are to be made the two tracings can be pinned together, registering from the crosses on each tracing.

Value of Moulding Machinery.—R. Carrick (*Mechanical Engineer*, 1917, vol. 39, p. 152) discusses the development of machine moulding. It is surprising what a small proportion of the inventive genius that has been busily engaged for generations in the evolution of labour-saving machines has been devoted to foundry machinery, and it is

only within comparatively recent years that machine moulding has come into extended use in other countries. There is, however, abundant evidence that the prejudice existing among foundrymen is gradually passing away.

The introduction of moulding machines in foundries is the subject of a paper read by A. O. Backert before the American Foundrymen's Association, Cleveland, September 1916. The paper contains many helpful suggestions from ironfounders who have been notably successful in the development of mechanical moulding practice in their plants. An investigation to ascertain the wage basis for machine operators showed that piecework prevails generally in shops where moulding machines are employed.

Influence of Gating on Castings.—B. D. Fuller, A. M. Fulton, and others (*Paper read before the American Foundrymen's Association, Cleveland,* September 1916) have studied the influence of gating on castings. Castings are gated largely by rule-of-thumb methods, and the authors have made an effort to show some of the principles underlying the gating problem. The paper is divided into four parts, dealing with the gating of grey iron, malleable iron, steel, and non-ferrous metal castings respectively. It is clearly brought out by each of the authors that there is an intimate relation between the location of the gate and the shrinkage problem. When castings are properly gated and are provided with suitable heads, there is very little trouble from shrinkage, and when this work is done correctly it is possible virtually to eliminate the use of chills in malleable practice. Chills should be avoided, since they simply drive the shrinkage to a part of the casting where possibly it may do harm. The correct gating of any casting is just as important as a proper mixture of metal and should have as much thought devoted to it as to any other feature connected with making the mould or pouring the casting. In designing any gate two points should be considered: First, can the casting be fed from the proposed gate, excluding slag and preventing miss-runs, and second, should the heavy portion be fed by a riser located at the top of the casting? The advantages of the bottom-pour, fountain, or horn type of gate for grey iron, malleable, or steel castings are emphasised. For certain forms of steel castings, such as rolls, special whirl gates are necessary. Proper gating is specially important in the production of non-ferrous metal castings, on account of the difficulties resulting from oxidation of the metal and the comparatively low temperature at which the metal freeezs.

Seasoning Castings.—R. Moldenke (*Bulletin of the American Institute of Mining Engineers,* No. 122, 1917, pp. 229–233) discusses the physical effect of the "seasoning" of iron castings. This is an easing up of the strains remaining after the final contraction. By the action of light blows, often repeated, the internal strains are relieved to such

an extent that the real value of the metal comes into play. This mobility of the molecules can be aided by artificial means, and six months' quiescence may be equivalent to half an hour's "tumbling."

Malleable Cast Iron, Air Furnace for.—F. C. Rutz (*Paper read before the American Foundrymen's Association, Cleveland,* September 1916) gives details of a 25-ton air furnace designed for melting malleable iron, and is of opinion that for a number of reasons this is the most satisfactory size. The operation cost of the 25-ton furnace is estimated to be \$3·25 per ton, compared with a cost of approximately \$3·85 per ton for 12- and 15-ton furnaces. The melting ratio with the 25-ton furnace, covering a year's tonnage actually poured, is said to be 2·75 to 1. The 25-ton furnace will do practically double the work of a 12- or 15-ton furnace. The article concludes with detailed dimensions of the 25-ton furnace.

A detailed description has appeared (*Iron Trade Review*, 1917, vol. 60, pp. 575–581) of the new air furnaces in the Buffalo Plant of the American Radiator Company, designed to eliminate skimming of the slag and to simplify the process of charging.

Fracture of Malleable Iron.—E. Touceda (*Paper read before the American Foundrymen's Association, Cleveland,* September 1916) calls attention to the fact that there is a difference in structure between the skin and core of a steel casting, as in a malleable casting, only in the former case it is not visible to the naked eye. When good malleable iron is broken in simple tension the grains become tapered down to a point, forming what is known as a "tooth." This results in the fracture having a somewhat different appearance when viewed by oblique light than that which it exhibits when viewed in a direct light. These differences are fully explained in the paper, which is illustrated by micrographs. If a bar of malleable iron is broken transversely, a silvery white area will appear on the compression side, and the more ductile the metal, the greater will be the depth of this area.

Cast-Iron Pipe Manufacture.—The cast-iron pipe industry in the United States, which has an output of about 1,000,000 tons per annum, is described by Y. A. Dyer (*Iron Age,* 1916, vol. 98, pp. 1159–1162). Most of this pipe is manufactured in the south and in the Birmingham, Alabama, district, and most of the works work continuously throughout the week. Improvements have of late been effected by increasing the standard length of pipe from 12 feet to 16 feet, with a large resulting saving in joints. Cupolas charged on an analysis basis are used for melting the iron.

A new centrifugal pipe-casting machine has been brought out by D. S. de Lavaud and F. Arens, and several such machines are operating in Brazil. The machine and its mode of operation are described (*Iron Age,* 1916, vol. 98, pp. 506–509).

Casting of Cylinder Linings.—F. Andrew (*Foundry Trade Journal*, August 1916, vol. 18, p. 423) gives an illustrated description of a method of making cast-iron cylinder linings such as are used in internal combustion engines.

Pickling Castings.—A note has appeared (*Foundry Trade Journal*, November 1916, vol. 18, p. 591) on the over-pickling of castings. Cast iron that has to be galvanised usually requires to be pickled first, even though it may have been "tumbled" or sand-blasted to clean it. After pickling, however, castings will sometimes be very difficult to galvanise, taking the zinc badly. This results from over-pickling, which allows the acid (either sulphuric, muriatic, or hydrofluoric) to attack the iron and expose the graphite excessively on the surface. This defect can be remedied by brushing and scouring until the carbon is removed, but if it is not given this treatment, but is put directly into the electro-galvanising solution, the zinc will not deposit on it well, the carbon being a poor conductor.

Mechanical Tests for Cast Iron.—F. J. Cook (*Paper read before the Staffordshire Iron and Steel Institute; Mechanical Engineer*, 1917, vol. 39, p. 89) points out that the important tests which are of use as a guide to the foundrymen are: (1) Keep's tests, shrinkage, deflection, and transverse; (2) hardness test; (3) casting temperature or fluidity test; (4) measurement of volume and pressure of cupola blast; (5) impact test; he gives some account of each.

Semi-Steel.—D. McLain (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) discusses the manufacture and properties of semi-steel. On account of its greater purity, it is considered more resistant to the action of heat and acid than grey cast iron. The most important point of difference between semi-steel and grey cast iron is in the formation of the graphitic carbon. In semi-steel this exists in exceedingly small flakes and granules, whereas in the other product the graphite is usually present in the form of large flakes. Classifications and analyses of semi-steel castings for special purposes are given. The paper is accompanied by a large number of micrographs, showing the structures of various semi-steel castings. Some facts also are presented relating to the hardening of semi-steel, and the author claims that this material has been used satisfactorily for dies and punches. He also states, however, that it is not believed that semi-steel will replace tool steel.

Steel Foundry Practice.—E. F. Lange (*Paper read before the Manchester Association of Engineers*, January 13, 1917) deals with the progress in the production of steel in various countries within the last decade, with particular reference to the manufacture of steel castings. Reference is made to the process for making Mitis steel castings, to

crucible steel foundry practice, and Bessemer steel foundry practice. The small converter process for the manufacture of steel castings has been more greatly developed in Belgium than in any other country. The output of steel castings in Belgium was quadrupled in the twelve years preceding the War.

J. E. Hurst (*Engineer*, November 24, 1916, vol. 122, p. 462) gives some notes on the melting of steel in the foundry cupola. The drawbacks to melting steel scrap in the cupola are the excessive loss through oxidation and the tendency of the sulphur content to be largely increased. By avoiding the very small and fine class of borings or using some briquetting process, the oxidation can be kept normal. With regard to sulphur the greatest care must be used in the selection of fuel. The addition of extra limestone with sand is an efficacious way of keeping down the sulphur and gives a more fluid slag.

J. H. Gray (*Steel and Iron*, February 1916, vol. 50, pp. 39–45, 52) writes on general practice in steel foundries using electric furnaces. Various types of such furnaces are illustrated, showing the chief features and efficiency of each.

E. F. Cone (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) discusses acid as compared with basic steel for castings.

V. C. Faulkner (*Foundry Trade Journal*, December 1916, vol. 18, pp. 633–637) in a paper read before the London Branch of the British Foundrymen's Association, October 27, 1916, discusses the production of light castings in the electric furnace.

C. A. Keller (*Foundry Trade Journal*, March 1917, vol. 19, p. 136) has invented an apparatus for keeping the metal hot when several furnaces are tapped into one ladle before pouring and the content of the ladle is apt to become too cool. The apparatus consists of two electrodes which can be raised and lowered from a crane or gantry. Current passing from one electrode to the other through the contents of the ladle generates enough heat to bring the contents back to the proper pouring temperature.

R. H. West (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) deals with theory and practice in gating and heading steel castings.

Alloy Steel Castings.—D. Evans (*Paper read before the American Foundrymen's Association; Iron and Coal Trades Review*, January 1917, vol. 94, p. 42) deals with the function of different alloys added to steel. Titanium disappears entirely when added to the charge. Its value is entirely as a flux. Assuming that the steel is ready for the addition of the alloys, the 50 per cent. ferro-silicon is first added, followed immediately by the titanium, 4 to 6 lb. of the latter to a ton of steel being recommended. In open-hearth practice from six to eight minutes should elapse between the addition of the titanium and the pouring of the first mould, but in converter practice the time may be

reduced to three or four minutes, which is sufficient for the slags and oxides to rise to the surface. Titanium has proved a safer deoxidiser than the use of aluminium, as the tendency to use too much often results in the formation of alumina in the finished steel. The action of titanium is to prevent the formation of a number of blowholes throughout the ingot and to concentrate them in one place near the top. It is of great benefit in pouring thin sections where clean, hot metal is especially desired, and a maximum of strength required. The high price of aluminium during the past year has done much to establish titanium in the steel foundry. As regards vanadium, steel is improved by its addition, but the full value will not be realised unless the steel is properly annealed. When ferro-vanadium is added, it goes immediately into solution. Through its affinity for oxygen and nitrogen it combines with those gases. This deoxidising effect, however, is purely incidental, and where it takes place to such an extent as to cause excessive loss of the alloy in the finished steel it is an indication that the steel was not properly deoxidised in the first place. To this extent it performs the same office as titanium or aluminium, but is far too expensive to be used for this purpose alone. The practice seems to be fairly uniform among steel founders to add 0·10 to 0·20 per cent. of vanadium. It is claimed that it has a peculiarly intensifying effect on the other elements in the steel, or on alloys added, such as chromium, nickel, or tungsten.

Titanium in Steel Castings.—In a paper read before the American Foundrymen's Association, W. A. Janssen (*Foundry Trade Journal*, December 1916, vol. 18, p. 647) expresses the opinion that, notwithstanding all that has been said regarding the harmful effects of phosphorus and sulphur in steel castings, occluded gases and oxides are the real causes of many of the troubles of the steel foundryman. He is of the opinion that in the elimination of these difficulties, ordinary deoxidisers such as ferro-manganese and ferro-silicon have their place, but if the best results are to be achieved, a more potent reagent is necessary, and for this purpose ferro-titanium has proved unusually satisfactory. Titanium undoubtedly is one of the most powerful deoxidisers and denitrogenisers known. The chief value and merit of titanium lies in its positive action in the removal of occluded oxides, nitrogen, and entrapped slags. Titanium, however, must not be expected to remedy the evils of poor stock selection and bad furnace practice. Its function is to make good steel better. In the present days of high-priced ferro-manganese, ferro-titanium can be used to advantage to decrease the consumption of the manganese alloy.

Manufacture of Manganese Steel Castings.—W. S. McKee (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) treats of the manufacture of manganese steel castings in a general way. Particular emphasis, however, is laid upon the

difficulties experienced by the manganese steel foundryman, and suggestions are given regarding the most accepted methods of solving certain manganese steel foundry problems. The paper opens with a description of the physical, chemical, and metallographic characteristics of manganese steel castings, following which the various details of foundry practice are discussed. It is pointed out that special problems are encountered at every stage in the manufacturing process, and that a wide experience is necessary. The paper takes up successively the problems encountered in making the moulds, mixing and pouring the metal, heat treating, finishing, and machining the castings. In conclusion some of the applications of manganese steel castings are described.

Manganese-Steel Wheels.—The manufacture of cast-steel wheels, with tread and flange of manganese steel, is described (*Electric Railway Journal*, 1916, vol. 48, pp. 69–71).

Cast-Steel Wheels for Motor Trucks.—An illustrated article has appeared (*Iron Trade Review*, 1917, vol. 60, pp. 465–471) on the manufacture of cast-steel wheels for motor trucks.

Chilled Car Wheels.—In a paper read before the American Foundrymen's Association in September 1916, G. S. Evans (*Foundry Trade Journal*, October 1916, p. 540), gives the results of a series of comprehensive tests of car-wheel mixtures made at the Lenoir Car Works, Lenoir City, Tenn. The tests, which extended over a period of two years, were undertaken to determine the relative strength of wheels made from mixtures containing varying percentages of coke and charcoal pig irons, when made under uniform foundry conditions. During the tests, wheels were cast from some sixty different mixtures, some of which carried as much as 60 per cent. scrap steel; others contained 85 per cent. charcoal and coke pig, and others still as much as 98·5 per cent. scrap wheels. The following were the conclusions arrived at: No gain in strength is obtained by increasing the percentage of either charcoal or coke pig iron beyond approximately 12 per cent. The substitution of charcoal pig does not result in any clearly defined beneficial effects on the strength of the wheels as shown by various tests. The effects, if any, of the different mixtures, on the microstructure of either the chilled or grey portions of the finished wheels is not of such a nature as to be clearly defined. The foundry practice, including the melting, casting, and annealing, appears to be largely responsible for the ultimate strength of the finished wheels.

Melting of Aluminium Scrap.—Special directions for the effective melting of aluminium chips are given by H. W. Gillett and G. M. James (*U.S. Bureau of Mines*, Bulletin 108, 1916, pp. 1–88). The many difficulties experienced in obtaining a clean melt from scrap are

detailed, and the use of a suitable flux containing 85 per cent. of common salt and 15 per cent. of fluorspar, used in large amounts, is advocated. High temperatures are required during the melting, and graphite crucibles or reverberatory furnaces are recommended, and the need for cleanliness is emphasised, as the presence of dirt leads to low recoveries.

Production of Aluminium Castings.—J. Gaunt (*Paper read before the London Branch of the British Foundrymen's Association; Mechanical Engineer*, 1917, vol. 39, pp. 323–325) deals with the production of aluminium castings.

Electric Furnaces in the Steel Foundry.—J. A. Crowley (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) gives details of the construction and operation of a Gronwall-Dixon electric melting and refining furnace installed in a plant at Detroit. The furnace works on a two-phase system, energy being taken from three-phase supply through two banks of transformers. The transformers are arranged to deliver current at varying voltages. The furnaces are built with either four or two roof electrodes and one bottom electrode, which does not come in contact with the bath. The arcs may be thrown either in series or in parallel, and the furnace may be operated in several intermediate positions between series and parallel. This permits of flexibility in melting and refining. The cost of liquid alloy steel, melted in the Gronwall-Dixon furnace, is stated to be $22.09 per ton. The conversion cost on steel castings in a 5-ton furnace is given as $19.41 per ton.

T. S. Quinn (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) gives the results of eighteen months' operation of a 1-ton Heroult furnace, during which period the results, on the whole, have been entirely satisfactory. Up to August 1, 1916, the furnace had made over 2000 heats on the original basic bottom. The lining lasted from 100 to 125 heats, and the roof from 125 to 150 heats. The electrode consumption was 25 lb. per ton of steel. With insufficient transformer capacity, the power consumption averaged 950 kilowatt-hours per net ton of steel. The process of operating the furnace is described in considerable detail, and in conclusion he points out that probably the electric furnace has been developed commercially before skilled melters could be trained, which may account for some of the difficulties encountered.

F. J. Ryan, E. E. McKee, and W. D. Walker (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) consider the single-electrode type of furnace to be the ideal electric melting furnace for the steel foundry. Such a furnace may be operated with either an acid or basic lining, as conditions may dictate. Special reference is made to the open-roof type of furnace, recently developed, for which a number of advantages are claimed. The paper is accompanied by several tables giving data covering the operation of single-

electrode furnaces in steel-casting plants in the United States and Canada.

The use of the electric furnace in the foundry is discussed by E. B. Clark (*Paper read before the American Foundrymen's Association, Cleveland,* September 1916), who presents a series of general observations on the subject based on experience, rather than a technical discussion. The four principal processes of making steel, in the crucible, the open-hearth furnace, the Bessemer converter, and the electric furnace are briefly described. The principal advantage of the electric furnace method of steel production, the author states, is the high quality of steel that it is possible to produce. However, a belief hastily arrived at that the electric furnace is a cure for all troubles in the steel foundry will inevitably lead to disappointment. The electric furnace has some marked advantages, but it also has some annoying disadvantages.

An illustrated description has appeared (*Iron Trade Review,* 1917, vol. 60, pp. 201–203) of a new electric steel plant owned and operated by the Belle City Malleable Iron Company, Wisconsin.

Cleaning Castings.—H. C. Estep (*Paper read before the American Foundrymen's Association, Cleveland,* September 1916) deals with cleaning-room problems and outlines in a general way the equipment for cleaning castings in certain representative foundries. A number of illustrations are presented showing typical cleaning-room installations in representative foundries, these illustrations being accompanied by descriptive data.

Remedy for Slippery Iron Plate Floors.—A description has appeared (*Foundry Trade Journal,* November 1916, vol. 18, p. 604) of a method for dealing with slippery iron plate floors. A small amount of powdered sal-ammoniac is taken and mixed thoroughly with a large quantity of fine sand. The mixture is sprinkled over the floor so that all parts are covered, and the whole mass is watered, using an ordinary sprinkling-can, and left to lie over-night. In the morning the sand is swept up, and the rust coating will last for several weeks, after which the process is repeated. It was found that this method involved less time and cost and was more effective than any other.

Foundry Fires.—F. H. Wentworth (*Paper read before the American Foundrymen's Association, Cleveland,* September 1916) deals with foundry fires in the United States. The record shows that 30·7 per cent. of foundry fires of known origin are caused by the cupola. The core-oven is the next greatest offender, being responsible for 15·3 per cent. of the total number of foundry fires. The records of the National Fire Protection Association show that there have been 475 foundry fires in the United States reported to the Association since 1906. The article concludes with a number of suggestions for fire prevention.

Foundry Economics.—H. W. Dunbar and W. E. Freeland (*Iron Age*, 1916, vol. 98, pp. 1383–1389) give an account of the method of storing drawings, blue prints, and records in a large modern foundry. The equipment for dealing with the largest-sized drawings is described and illustrated in detail.

The co-ordination and adjustment of the estimating, designing, production, and manufacturing departments of large works are dealt with by A. D. C. Parsons (*Ibid.*, pp. 1390–1393).

An Eighteenth-Century Moulding Shop.—J. Horner (*Foundry Trade Journal*, 1916, vol. 18, pp. 532–534, 577–578) gives an illustrated description of a moulding shop described in the great French Encyclopædia of 1765. The foundry was one of pre-cupola days, for the castings were run direct from the blast-furnace without remelting. But as the iron was smelted with charcoal and with cold-blast, the quality of the metal was much superior to that of the iron smelted to-day. The same furnace and the same metal were used to run the long pigs for the refinery, and the metal for the castings. This practice was similar to that adopted at Coalbrookdale at the same period.

PRODUCTION OF STEEL.

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I.—*PROCESSES OF STEEL PRODUCTION.*

Production of High-Speed Steel in the Crucible and Electric Furnace. —A conference on electric furnace steels was held at New York on the occasion of the Exposition of Chemical Industries in October 1916 (*Metallurgical and Chemical Engineering*, vol. 15, p. 448). Amongst the subjects discussed were the suitability of such furnaces for the making of alloy and high-speed steels as compared with crucible steel furnaces, and the relative advantages of cold and hot charges. Electric steels were regarded as freer from non-metallic inclusions than open-hearth and Bessemer steels and to have wider forging and hardening ranges. Power costs were also discussed.

In another report of the same discussion (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 552) it was stated that while the crucible was not adapted to making high-grade low-carbon steels, high-grade carbon and alloy steels could be produced cheaper in the electic furnace. As to the relative merits of high-speed steel made in the crucible or in the electric furnace, probably 50 per cent. of such steel now made in the United States is made in the electric furnace, and it would be impossible to select one from the other. The advantage of the electric furnace was not as great for high-speed as for alloy steels.

R. C. McKenna (*Mechanical Engineer*, 1917, vol. 39, pp. 211–212) deals with the manufacture of crucible tool steel.

Tilting Furnaces.—An illustrated description has appeared (*Mechanical Engineer*, 1917, vol. 39, p. 90) of a tilting furnace invented by D. F. Campbell and the Société Electro-Metallurgique Française, Isere. With tilting furnaces it is the usual practice during the teeming process to swing the ladle under the spout of the furnace by means of a crane, by which also it is afterwards transferred to the mould into which the liquid is to be poured. In the present arrangement the crane is

dispensed with and the ladle, placed on a carriage, is run underneath the lip of the furnace, and during the process of teeming is temporarily supported on arms projecting from the furnace bed. When the lip of the furnace is slightly tilted upwards the carriage is withdrawn, and the furnace is then tilted downwards in order to pour the contents into the ladle. When the teeming operation is finished the furnace and ladle are tilted back to the position in which the carriage can be again run underneath the ladle, the furnace is then slightly tilted to lower the ladle on to the carriage, and the arms are disengaged from the ladle. The furnace described has the advantage that not only no crane is required, but there is no possibility of spilling any of the molten material in the process of filling the ladle. The weight of the ladle also forms a convenient counterpoise to the gear for operating the electrodes.

Duplex Process.—G. B. Waterhouse (*Iron Age*, 1916, vol. 98, pp. 999–1001, 1035–1037) gives an account of the method by which the duplex process is carried out at the works of the Lackawanna Steel Company. The plant consists of two mixers of 250 and 300 tons capacity respectively; four 12-ton converters and twelve cupolas, as well as two large tilting furnaces, and eight stationary 100-ton furnaces. The process employed runs continuously throughout the week, beginning at 6 P.M. on Sunday, when the slag is prepared for the tilting furnace by charging burnt lime and roll scale. Some hours after metal is ordered from the Bessemer Department; 28,200 lb., from two heats blown in different vessels, are taken, the composition being about 0·370 carbon, 1·50 silicon, 0·65 manganese, 0·045 sulphur, and 0·360 phosphorus per cent., before blowing. The first ladle contains about 0·40 per cent. carbon, to give a little action in the furnace, and is followed by two ladles of soft metal, which has been blown down to 0·05 or 0·07 per cent., and then by a high ladle, or "kicker." A vigorous reaction takes place; the metal and slag are thoroughly mixed together, and during this reaction the phosphorus is largely removed from the metal to the slag. Two more "soft" and one "high" ladle are subsequently charged, and then ladles high or low according to the then composition of the bath, which now amounts to 190 or 200 tons. The charge is then worked down like an ordinary basic open-hearth heat and, the first pouring of metal having taken place at about 12·45 A.M., the first tapping usually takes place at about 3.30 A.M., 100 tons being retained in the furnace. Lime, scale, and dolomite are again charged and further working proceeded with on lines which are fully explained. Details of the life of the furnace and of the number of heats are given. The general arrangement of the furnaces, with plans and sections, is shown, and typical analyses of the materials forming the charge are given, together with the number of heats and tonnage of ouput of two furnaces for nine months in 1915 and eight months in 1916.

Triplex Process.—The triplex process (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 552) is being employed by the United States Steel Corporation at Joliet, Ill., where two 15-ton Heroult furnaces are operating, chrome bricks being successfully used instead of magnesite. The question of the relative quality of electric steel made from hot or cold metal was discussed at the Convention of the American Chemical Society in September 1916, and it was stated that the dead melt and the deoxidation obtainable were potent factors in producing superior steel. G. B. Waterhouse advocated the use of an electric furnace with an acid lining in connection with the Bessemer and open-hearth, as in the triplex process, as sufficient refining was possible before the electric furnace stage was reached.

Premelting Ferro-Alloys.—B. P. Wheeler and T. S. Blair, Jun. (*Foundry Trade Journal*, September 1916, vol. 18, p. 469), have patented a device which is claimed to be an improvement in open-hearth furnaces. It comprises a melting compartment, built as an extension to the back wall of the furnace, in which ferro-manganese and other final additions are melted by the heat of the furnace. A cross-section of the furnace is shown, illustrating the additional chamber for premelting the ferro-alloys.

Fluorspar.—E. F. Burchard (*U.S. Geological Survey, Mineral Resources*, 1915, Part II. 6, pp. 33–41) reports on the production and consumption of fluorspar in the United States and Great Britain, the demand depending on the rise and fall in the production of steel.

German Steelworks.—The basic-Bessemer installation of the Aumetz-Friede Company, Kneuttingen, Lorraine, has been reconstructed and modernised (*Iron and Coal Trades Review*, December 1916, vol. 93, pp. 758–759). The plant now consists of six converters, arranged in a straight line with two mixers of 800 tons and 1400 tons capacity respectively. The capacity of the plant has been increased from 720 tons to 1000 tons of blown steel per shift.

Roll Scale in Bessemer Practice.—The use of roll scale in the Bessemer process is discussed by A. Patton and F. N. Speller (*Bulletin of the American Institute of Mining Engineers*, No. 122, 1917, pp. 139–148). The object of using scale is to shorten the blow and so produce more material from the same plant. The best way of charging it was found to be placing it in the empty vessel so that when the molten iron was poured into the vessel it flowed over the scale, causing a considerable reaction to take place before the heat was turned up. Eventually cylindrical chutes were installed and the scale dumped into them and so carried to the empty vessel. The ratio of increased production on using roll scale at the Ohio Works, Youngstown, where the process has been in use for at least twenty years, was as 107 : 80. The proper use of roll scale, pig, and scrap enables the blower to turn down his

heats nearer to the same point in carbon by giving a sharper contrast on the final changes in the flame, which makes the loss in manganese and the amount of residual manganese in the steel likewise more constant. It also economises the iron which would otherwise be burned at the expense of the charge, hence, to maintain the thermal efficiency, higher silicon needs to be present. With a converter properly designed to meet changes in the composition of the iron, the use of roll scale is a great time-saver. Tables are given showing the effect of this in current practice. Although better steel, increased production, and lower cost are claimed as the results of employing roll scale, its use is not advanced as a "cure-all," as to obtain the best results requires close study of the conditions to be fulfilled.

Temperature Measurements in Bessemer and Open-Hearth Practice.—G. K. Burgess (*Bulletin of the American Institute of Mining Engineers*, No. 122, 1917, pp. 293–303) shows that, so far as casting temperatures of streams of iron and steel are concerned, well-known pyrometric methods may be easily applied for their ascertainment, if certain recently determined corrections are made and precautions taken. Greater difficulties are encountered in respect to open-hearth temperatures, while converter temperatures present insuperable difficulties. Optical pyrometers using monochromatic light and permitting observation of streams of metal from a distance are best suited, and corrections have to be applied for the probable values of emissivity, which are determinable in regard to metals and oxides, but uncertain in regard to slags. Bessemer operations are not, however, practicable by pyrometric methods, but in practice teemers require a remarkable degree of uniformity in deciding casting temperatures. Tables showing apparent temperatures of metal when poured and in the ladles are given.

Utilisation of Waste Heat from Open-Hearth Furnaces.—A. D. Pratt (*Paper read before the American Society of Mechanical Engineers*, December 1916; *Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 696–708; 1917, vol. 16, pp. 27–31) considers the development and use of the modern waste heat boiler in connection with open-hearth steel furnaces, beehive coke-ovens, heating furnaces, &c. In modern waste heat practice an induced draught is used to produce the gas velocity necessary for a satisfactory rate of heat transfer; in certain classes of work such draught has the additional advantage of improving the operation of the primary furnace.

In most cases the saving effected by the use of waste heat boilers lies mainly in the value of the power produced by the steam generated. At the present time such boilers are most largely employed with open-hearth steel furnaces, and in this connection have been the means of reducing the net cost of producing steel by 10d. to 1s. 0½d. per ton.

Plans and elevations are given of a waste heat boiler applied to an

open-hearth furnace, and tables showing the results of tests at several large steel plants at various places in the United States. The chief sources of loss are air leakage, while the best results are obtained when the gases from the furnaces used for steam raising are cleaned. The effect on exit-gas temperatures is very marked.

Air Valve for Liquid Fuel Furnaces.—An illustrated description is given of a patent recently taken out by H. E. Yarrow (*Mechanical Engineer*, 1917, vol. 39, p. 308) for a valve for controlling the flow of air to a furnace burning liquid fuel. The valve is adapted to control the supply of air, and at the same time to act as a safety device to prevent, in the case of a " blow back " or rise of pressure in the furnace, the escape of air, gas, or steam into the stokehold.

Electric Steel Furnaces.—The Greaves-Etchells electric furnace, a Sheffield furnace of a new type, is described and illustrated (*Iron Age*, vol. 99, pp. 140–141 ; *Iron and Coal Trades Review*, February 1917, vol. 94, pp. 119–120). It is specially designed for the manufacture of high-speed and high-grade alloy steels. The system adopted consists in applying bottom heat to the furnace by means of a bottom electrode, and in creating such electro-magnetic effects that the bath of molten metal is continually in circulation. Energy is supplied through a conducting hearth as well as by two or more top electrodes ; three-phase current is employed. The special feature of the furnace is that three single-phase transformers are used connected with meshed primaries. The secondary windings are connected in an unequal star, one leg of which is joined to the bottom electrode and the other leg to the top electrodes. The claims made for this system are :

1. That the proportions of the unequal star are so calculated as to give a balance on the primary supply phases when the upper electrodes are in equal adjustment.

2. If one arc is broken the others are not affected, and any current overload passing through any arc must traverse two transformers in series and in different phase. Continuous load can thus be maintained with very little variation either up or down, insuring the full capacity of the transformer being employed.

Among the metallurgical advantages are the fact that the steel is uniformly heated, the intense heat of the arcs being constantly absorbed by a moving stream of metal.

F. J. Ryan, E. E. McKee, and W. D. Walker (*Paper read before the American Foundrymen's Association*, September 1916 ; *Iron and Coal Trades Review*, 1916, vol. 93, p. 426) advocate the single electrode type of furnace as the ideal electric melting medium for the steel foundry. Such a furnace has been perfected by the Snyder Electric Furnace Company, Chicago. A summary is given of the results obtained in a $\frac{3}{4}$-ton single-electrode furnace in the plant of the Gerlinger Steel Casting Company, Milwaukee. The output during January,

February, and March 1916 was 274·23 tons; the total electricity, 146,160 kilowatt-hours; average kilowatt-hours per ton, 533; average lb. per heat, 1885; average cost per ton of metal in the ladle, £6.

This furnace was basic lined. It was guaranteed to produce 3 tons of steel per twelve hours with power consumption at the furnace not in excess of 880 kilowatt-hours per ton of steel. In actual practice the furnace has often produced four heats of 2000 lb. for a total of 4 tons in slightly more than eleven hours. The power consumption on the primary side of the transformer averaged only 533 kilowatt-hours per ton over the period of three months. A larger single-electrode furnace has since been installed by this company and is now operating with satisfactory results.

An illustrated description is given (*Iron and Coal Trades Review*, March 1917, vol. 94, p. 243) of a Girod furnace installed by the Bethlehem Steel Company for the production of high carbon and alloy steels formerly produced by the crucible method.

According to Miolati (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 489) in Italy the Stassano electric furnaces have given and are still giving excellent results in the hands of capable technical men. There are at the present moment several under construction and others which are to be substituted for electric furnaces of other types. At Dalmine the Italian Mannesmann Tube Company has two Heroult furnaces; at Lovere (Bergamo) a Kjellin-Rodenhauser induction furnace was installed, but not having given satisfactory results has been replaced by a Stassano. The Ansaldo firm, which already possesses a Girod furnace, is installing a Stassano. For the production of special steels the completely enclosed Stassano furnace is found particularly suitable.

The electric steel furnace plant of the Clark Equipment Company, Buchanan, Michigan, is described and illustrated (*Iron Age*, 1917, vol. 99, pp. 133–137). The furnaces are of the Heroult type and supersede the two Stassano furnaces originally employed for the manufacture of steel castings.

An illustrated description is given of the electro-metals two-phase electric arc furnace (*Iron and Coal Trades Review*, January 1917, vol. 94, pp. 87–90). The furnace is lined with dolomite on magnesite bricks which rest on a carbon mixture 1 inch thick. The roof and sides are of silica brick. The furnace is supported on rockers and is fitted with a tilting gear and an electrode adjusting gear. The electrodes are held in specially designed holders and their adjustment can be effected by hand during the starting up and afterwards automatically. Two single-phase step-down transformers can be used when there is a suitable public supply, but in most cases it is necessary to arrange the transformers to change three-phase to two-phase. The advantages of two-phase furnaces are given, and it is shown that the bath of molten metal in the furnace is equivalent to a movable conductor in a rotating field and consequently will be dragged round in the direction of the field.

The vertical circulation of the charge in the furnace is a valuable feature for the following reasons:

(*a*) It takes away hot metal from the surface directly it is formed, thus reducing radiation of heat to the roof and preserving the brickwork.

(*b*) The bath of metal is kept at approximately the same temperature, thus avoiding overheating and underheating.

(*c*) The circulation brings each portion of the metal into contact with the slag, thus facilitating the refining operation.

(*d*) Occluded gases are released.

A description is given of the method of working the furnace.

A two-phase furnace for 7½ tons per charge, fitted with 12-inch electrodes, requires about 10,000 amperes per phase at 80 volts and 50 periods per second, and at a power factor of 0·8 takes 2000 kilowatts.

Electric Furnaces in Norway.—A short account is given (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 641) of the recent development in electric furnace installations in Norway, and the names of the principal companies who have put down new installations are mentioned.

Manganese in American Steel Metallurgy.—The functions of manganese, more especially from the standpoint of American practice in steel-making, are discussed by F. H. Willcox (*Bulletin of the American Institute of Mining Engineers*, No. 122, 1917, pp. 199-207). As deoxidisers manganese, aluminium, silicon, and titanium, and to a lesser degree certain rarer or more expensive elements, have been used, but ferro-manganese is the principal. Before the war very little ferro-manganese was used in America, but the import of manganese ore in 1916 may be estimated as more than double that imported in 1915. The bulk, in a proportion largely increasing, comes from Brazil. Even so, the supply falls far short of the demand, and two alternative modes of remedying the deficiency are suggested. One is the accumulation of a reserve of high-grade manganese ore to tide over a twelvemonth stoppage, should this occur at any time. This would involve extensive and unremunerative capital outlays. The other is to find an efficient substitute. This has been tried in Germany, but with doubtful results, as the quality of the steel is, according to Dutch accounts, deteriorating, and the reason is said to be lack of manganese and of skilled workmanship. Much work remains to be done in metallurgy before an efficient substitute for manganese can be currently employed in practice.

Ferro-Manganese in Germany.—E. F. Cone (*Iron Age*, 1916, vol. 98, pp. 1453–1455) deals with the German situation in regard to ferro-manganese supplies. The composition of shell used by the Germans has long shown a manganese content below the normal, but as the steel is quite suitable for the purposes for which it is used, it is evident that a substitute is being used, although it is known that large stocks

of manganese ores were held in German works when war broke out. It has been suggested that an alloy of aluminium and silicon is being used, but, on the other hand, doubts have been expressed as to whether such a substitute would not be too expensive, and therefore industrially impracticable. Quotations are made from British trade and other papers showing the speculations that have been indulged in from time to time as to what the substitute spoken of really is, and the weight of the evidence is regarded as pointing to the conclusion that the use of slags containing manganese has been largely practised, although it is likewise considered possible that calcium silicide has been used.

Manufacture of Steel for Automobiles.—D. N. A. Blacet (*Iron Trade Review*, 1917, vol. 60, p. 418) compares the prevailing method of steel manufacture previous to the perfection of the automobile. As the automobile, with its rapidly moving parts actuated by high-powered motors, has in a sense become standardised, so has the manufacture of steel, which plays so important a part in its construction, progressed. Consistent with the selection of crude materials which furnish the fundamentals for the manufacture of steel for automobiles is the care observed in the use and composition of the ferro-alloys and metals added intentionally to the bath for the purpose of obtaining distinctive characteristics in the resultant steel. The precaution of analysing the ferro-alloys profits the manufacturer in two ways—the salvage of the heat of steel and efficiency in the use of alloys, especially the more expensive alloys. It is pointed out that there are many safety practices in the manufacture of steel for which the automobile has been responsible, and the methods adopted by manufacturers for safeguarding their products include double inspection for seams and other surface defects; also pickling certain steel billets to show more plainly the surface defects.

Basic Slag as affecting Agricultural Development.—D. A. Gilchrist and H. Louis (*Journal of the Society of Chemical Industry*, 1917, vol. 36, pp. 261–264) discuss the importance of basic slag to the agricultural industry. The discovery by Gilchrist and Thomas that it was possible to transfer phosphorus from iron to the slag in making steel, gave rise to the Gilchrist-Thomas or basic Bessemer process of steel-making, and it was soon found that the slag produced in this operation possessed valuable manurial properties. Basic slag thus came into competition with rock phosphate; the German chemists, whose object was to push the sale of the former, discovered that whereas the calcic phosphate in rock phosphate was practically insoluble in citric acid, that in basic slag was readily soluble in that acid, and they succeeded to a large extent in persuading agriculturists that the fertilising value of all phosphates depended not upon the percentage of total phosphoric acid, but upon the percentage of citric soluble phosphoric acid present. It does not

appear that this dictum was supported by any definite field experiments. When the manufacture of basic open-hearth steel commenced in this country, the slag produced by it was forthwith discredited as a manurial agent, simply because the slag produced by this process contains but little of its phosphoric acid in the citric soluble form. The reason assigned for this difference by Dr. J. E. Stead and others, is that whereas calcium phosphate is but slowly attacked by citric acid, the silico-phosphate is attacked readily (*Proceedings of the Cleveland Institution of Engineers*, January 1895). Pig iron suitable for the basic Bessemer process must be relatively high in silicon, and its treatment in the converter produces silico-phosphates, whereas for the basic open-hearth process, pig iron is required to be as low as possible in silicon, so that practically the whole of the phosphorus is converted into calcium phosphate.

It is only within recent years that experiments have been conducted with the object of determining whether the citric soluble phosphoric acid has such greater manurial value than the insoluble phosphoric acid as has been ascribed to it by the Germans. Trials conducted at Cockle Park, the Northumberland County Agricultural Experiment Station, from 1907 till 1915, on meadow hay and on temporary seeds mixtures for three years, show that in only one case out of five have slags with high citric solubility given the best results. The medium citric soluble slags gave the best results in one case out of two. The balance of results does not indicate that a high citric solubility gives either quicker or better results. The total phosphoric acid content is a far more reliable test of manurial value, and possesses the further advantage that it depends on the definite analytical determination of a substance, and should therefore be authoritatively substituted for the citric solubility test throughout the country.

Preparation of Tungsten.—A description is given (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 636) of the process of manufacture of tungsten powder at the Widnes Works of High-Speed Steel Alloys, Ltd. A list is also given of the firms having an interest in the company. The process of manufacture consists in first converting the tungsten oxide in the wolfram ore into a soluble tungstate of soda, precipitating it as an oxide, and then reducing this pure oxide to metal. The ore is first ground to a fine powder, it being necessary to obtain an intimate mixture with the soda ash. After mixing with the soda, the ore is taken to reverberatory coal-fired furnaces for roasting the mixed ore and soda ash. The fuel is fed on one side, and the furnace products on the opposite side. The mixed materials are roasted at a dull red heat, and the product is tapped in a pasty condition into iron ladles. The furnaces have a capacity of a half-ton per day each.

The roasted tungstate product is then taken to the end of the building, where it is broken up first in a stone breaker, and then ground in a

Carter disintegrator, from which it is conveyed automatically into the next department.

The furnace product is now boiled with water, and the tungsten, which has been rendered soluble in water by the action of the soda, is removed from the other constituents of the ore by passing through a filter-press. All the tungsten is thus collected as a solution of tungstate of soda. The residue, consisting of iron, manganese, and tin, is tipped on to the dump. The tungstate of soda solution is then boiled with hydrochloric acid in closed teak vats for ten minutes, and the precipitated solution of tungsten, now in the form of a yellow hydrated oxide, is run into a series of settling vats, where the mother liquor is run off, and the precipitate thoroughly washed to remove the last traces of the common salt mother liquor.

After washing and settling, the tungsten oxide is first dried to a paste in Broadbent centrifugal separators. The final drying takes place in reverberatory furnaces, where the calcined ore is finally withdrawn at a dull red heat. The calcined oxide is then mixed with carbon in mortar mills enclosed in a sheet-iron casing, and as discharged is placed in graphite crucibles and taken to the furnace house, where the oxide is reduced to metallic form.

At present coke-fired furnaces are used, but these are being replaced by a new continuous gas-heated furnace, having an arrangement at the discharge end for cooling the crucibles, whereby the spent gas is first used for re-heating the air before mixing with the producer-gas, while the cooled burnt gas is used for cooling the crucibles.

After reduction the crucibles, with their charge, are taken to a sorting room, where the contents are dumped on to benches. The crucibles always contain a certain amount of oxide, and this is separated for further treatment. The metallic powder is then taken to open cast-iron pans, where it is treated by hand stirrers with a weak solution of soda to remove the last traces of oxide, and the final metallic powder is then dried on a hot plate and is ready for shipment, containing 98 to 99 per cent. of pure tungsten and about 0·2 per cent. of carbon. The output is about 3 tons a day of tungsten powder of a purity exceeding 98 per cent.

Metallurgy of the Rarer Metals.—J. W. Richards (*American Institution of Chemical Engineers; Electrician*, 1916, vol. 77, pp. 675–677) discusses the modes of extraction of some of the rarer metals which at present are very expensive, but might be much cheapened if improved metallurgical processes were devised. Among others, the author refers to chromium, titanium, molybdenum, zirconium, and cerium.

Conservation of Health in Steel Works.—J. A. Watkins (*U.S. Bureau of Mines*, Technical Paper 102, 1916, pp. 1–36) reports on the measures to be taken for preserving healthy conditions in steelworks

and gives suggestions for the prevention of disease and the maintenance of efficiency.

An account is given (*Iron Trade Review*, 1917, vol. 60, pp. 569–572) of the welfare work for the employees of Messrs. Schneider & Co. at Creusot, which is also carried out at their other plants.

II.—*CASTING AND TREATMENT OF INGOTS.*

Standardisation of Ladle-Test Ingots.—J. R. Cain and H. S. Rawdon (*Proceedings of the American Society for Testing Materials*), 1916, vol. 16, Part I., pp. 129–144) report on an investigation of ladle-test steel ingots. Preliminary inquiries showed that there was a great diversity in the shapes and sizes of test ingots in current use by steel manufacturers; thirty-nine companies who sent in particulars of size and shape were found to be using seven different types of ingot. Systematic investigation is being carried on with a view to making recommendations of standard types, and a large amount of preliminary work has been done. About twenty-five test ingots submitted by steelworks have been examined, with the result that fifteen were found to be non-homogeneous as to carbon, nine as to sulphur, and nine as to phosphorus. The sulphur and carbon appear to behave somewhat similarly in that a sulphur difference is usually accompanied by a carbon difference, but not always *vice versa*. It is believed there is a tendency for deoxidation in the regions surrounding the blowholes whose walls are covered with oxide scale, and the effect of this would be to reduce the carbon content of the metal in such areas. A number of analytical results and many micrographs are given and plans for further work are laid down.

Reducing Piping in Ingots.—J. E. Shaeffer (*Mechanical Engineer*, 1917, vol. 39, p. 252) has patented a mixture for reducing piping in steel ingots and castings. The new compound, for which excellent results are claimed, consists of pulverised anthracite coal, mixed with a petroleum oil, the oil being in such proportions as to make a plastic mass which is placed on top of the molten steel immediately after it has been poured in the moulds. Because anthracite coal has a tendency to coke together during combustion and form a clinker, the coal alone cannot be successfully used to protect the surface. Instead of following the contour of the steel as it cools, the coal tends to clinker, thus bridging over the space, holding the protecting coal away from the steel at one or more points. The addition of petroleum is claimed to overcome this tendency, so that the protecting compound will follow the contour of the steel as it cools, affording efficient protection. The mixture recommended is 1 quart of petroleum to 100 lb. of carbonaceous material.

Influence of Gases in Molten Steel.—J. E. Fletcher (*Paper read before the Birmingham Branch of the British Foundrymen's Association; Mechanical Engineer*, 1917, vol. 39, pp. 274–278) has written a detailed account of the influence of gases in molten cast iron and steel.

Inclusions in Steel.—G. F. Comstock (*Paper read before the American Foundrymen's Association, Cleveland*, September 1916) deals with the presence of alumina in steel, the objects of the paper being to call attention to the fact that alumina can be distinguished from other non-metallic inclusions in steel, to indicate how it can be recognised, and to show a few examples of the harm arising from it when locally abundant. The difference between inclusions of alumina and ordinary slag or silicates in steel may be summarised as follows: (1) Silicate inclusions generally will take a fairly smooth polish, while alumina is very hard to polish without pitting. (2) Silicate inclusions are always elongated in the direction of rolling or forging, while alumina particles are not. (3) Silicate inclusions of large size are often found, while alumina particles are always small. They do not seem to coalesce into large bodies even when closely grouped together. The appearance of alumina is believed to be distinct, so as to warrant the identification of this substance in steel by metallographic examination. The author's work in establishing this identification was based largely on checking the microscopic evidence by chemical analysis. Large streaks of alumina in steel may not be common, but nevertheless they do occur when aluminium is used, and may cause great harm.

FORGING AND ROLLING-MILL PRACTICE.

Drop-Forging.—A. E. Sanford (*American Drop Forger*, March 1917, pp. 73–74) describes the sequence of operations in the manufacture of thin-walled stoppers and spouts from light-gauge stock, noting the points requiring special attention, such as the setting of blanks and partially finished pieces so as to avoid stretching.

P. Baldus (*American Drop Forger*, March 1917, pp. 80–83) gives a method for finding quickly the diameters of blanks for drawn cups without consulting tables or data sheets. Drawings of the punches and dies are shown.

Cast-Iron Drop Forge Dies.—A. R. Braden (*American Machinist*, 1916, vol. 45, pp. 621–625) describes a method of making cast-iron dies. The making of the patterns appears to be the most important part of the process, the latest plan being to use a pattern entirely of plaster, which is run into a cast-iron frame in which a wood model of the forging is placed. The patterns for the breakdown, anvil, sprue, and cut off are sawn out of wood and placed in their proper positions inside the frame before running in the plaster. The maximum time for turning out cast-iron dies is four days, and on one order a pair of cast-iron dies produced 5000 forgings.

Pressing and Stamping of Metals.—O. Smith (*Engineering Magazine*, 1916, vol. 51, pp. 855-868; vol. 52, pp. 83-89) describes the general function and construction of modern metal-pressing machinery. Presses of small, medium, and large size are discussed in detail, with particulars of dies of various kinds.

Rail Rerolling Mill.—The new rail rerolling mill of the Interstate Iron and Steel Company, Chicago, at its plant at Marion, Ohio, is described and illustrated (*Iron Age*, 1916, vol. 98, pp. 1446-1448). It is intended for the production of bars and shapes as well as rails, and has an estimated production of 4000 tons monthly. The objects aimed at in the lay-out have been a straight-line process from raw material to finished product, and the reduction of manual operations to a minimum. The rails are broken to 15-foot lengths and charged into furnaces containing from 75 to 90 pieces, or about 5 tons. They are heated continuously and delivered at the rate of 50 tons per hour, the furnaces being of the reverberatory type, coal-fired.

Lamberton Mill, at the United States Steel Corporation's Works, Ohio.—An illustrated description of the United States Steel Corporation's plant and equipment at Canton, Ohio, is given (*Iron Age*, 1917, vol. 99, pp. 73–77), including the new Lamberton mill. This is a 26-inch mill for rolling billets and bars, containing many modifications not hitherto adopted in Great Britain. The mill building is 416 feet long and 75 feet wide. The rolls are 26 inches in diameter and 96 inches long, and are driven by a Westinghouse 1500-horse-power alternating-current motor at a constant speed of 65 revolutions per minute.

Tire Mills.—Modern methods of tire manufacture and the practice of tire mills making weldless steel tires for locomotives and tramway cars are dealt with by G. Aertsen (*Bulletin of the American Institute of Mining Engineers*, No. 121, 1917, pp. 69-74).

Roll-Drafting.—W. S. Standiford (*Blast-Furnace and Steel Plant*, April 1916, pp. 162–164) gives notes on rolling-mills and roll drafting for the manufacture of steel bars for use in making munitions. Rolls of the following types are shown: Three-high roughing rolls, arrangement of strand rolls, a two-high stand of ovals, and a design of finishing rolls. The whole lay-out is intended for rolling $1\frac{1}{8}$-inch steel bars.

Sheet-Rolling Practice.—C. C. Lynde (*Blast-Furnace and Steel Plant*, 1916, vol. 50, pp. 121–124, 165–169) publishes some particulars of installations for sheet-rolling and practice in the rapid production of sheets.

Cold-Rolling Steel Strip.—E. K. Hammond (*Machinery*, September 1916, vol. 23, pp. 1-6; *Journal of the American Society of Mechanical Engineers*, 1916, vol. 38, p. 829) describes the operations connected with cold-rolling steel strip. The rolls are lubricated with a special grade of oil known as "Roll Oil," very carefully compounded so as to contain neither acid nor alkaline admixtures, as either condition spoils the bright surface of the cold-rolled strip.

Rolling of Wide-Flanged Beams.—F. Denk (*Blast-Furnace and Steel Plant*, November 1916, pp. 512–513; December, pp. 562–563, 566; January 1917, pp. 7–8, 11–12) describes different types of mills for rolling wide-flanged beams; with regard to the shape of section, parallel flanges or flanges with faces partly parallel and partly tapered are becoming a necessity, on account of the uses to which such beams are to be put. The design of rolls suitable for rolling beams with wide parallel flanges is discussed, with illustrations.

Reversing Engines for Rolling-Mills.—W. Trinks (*Blast-Furnace and Steel Plant*, January 1916, vol. 50, pp. 10–12 *et seq.*) considers various types of reversing engines for rolling-mill driving. The rolling

time may be reduced by lengthened acceleration and by plugging the engines, but figures are given to show that the practice of plugging increases the steam consumption of the engine from 30 to 50 per cent. Many calculations relating to rolling operations are given.

Steam Power *versus* Electricity for Driving Rolling-Mills.—W. Trinks (*Blast-Furnace and Steel Plant*, December 1916, pp. 558–561) compares the efficiency of the uniflow engine with that of the electric drive for rolling-mills. The number of actual installations is insufficient at present to enable average practical results to be obtained for comparison, but from personal experience with uniflow engines the author concludes that such an engine directly connected to the mill will be less costly to instal and run than a turbine with generator, switchboard, motor, and gear drive.

Gas Power *versus* Steam Power in Rolling-Mills.—R. H. Rice and S. A. Moss (*Proceedings of the Engineers' Society of Western Pennsylvania*, 1917, vol. 33, pp. 81–115) have carefully calculated the comparative economy of turbo-generators and gas-engines using surplus gas for power supply in rolling-mills, taking all costs into account. The first costs are found, and from them are computed the fixed charges at the rate of 13 per cent. To this are added running charges and cost of make-up coal. A small amount of make-up coal is used in the gas-engine plant to equalise poor gas and excess power demand, and a somewhat larger amount is used in the turbine plant. The first cost of the gas plant is about two and a half times that of the steam turbine plant, so that taking account of fixed charges the total working cost of the gas plant is about twice that of the steam turbine plant. This item of cost is so influential that the steam plant will always show lower total charges than a gas plant if fixed charges are included.

J. D. McArthur (*Paper read before the Institute of Marine Engineers*, November 1916; *Iron and Coal Trades Review*, November 1916, vol. 93, pp. 582–583) proposes that in order to utilise coal to the best advantage a great development in the use of internal-combustion engines as prime movers should take place from now onwards, but that the heavy oil engine, being only permissible within certain limits, must yield place to gas for power installations.

Electric Driving of Rolling-Mills.—W. Knight (*Electrical World*, 1916, vol. 68, pp. 662–665) analyses the requirements in connection with the electric driving of rolling-mills. With a flywheel on the motor provision should be made for the motor to have a large amount of slip, otherwise there is only a small drop in the speed of the flywheel when the load comes on and only a small percentage of its energy can be given up, thus causing most of the load to fall on the motor. The slip is arranged for artificially. The relative advantages of a heavy flywheel or a large-capacity motor are considered.

W. Sykes (*Paper read before the Engineers' Society of Western Pennsylvania*, October 1916 ; *Iron and Coal Trades Review*, November 1916, vol. 93, p. 543) describes some electrically driven reversing rolling-mill installations in the United States. The largest installation at present in operation is that of the Bethlehem Steel Company, which drives the 35-inch blooming-mill at the Lehigh plant. There are eighteen electrically driven reversing rolling-mills installed or building in the United States and Canada, including one working since 1907. Five of these are at work. The following particulars are also given as to power consumption and costs of maintenance and operation :

	1914.	1915.
Operating	8 Months.	12 Months.
Tonnage	92,622	174,460
Kilowatt-hours per ton	22·8	21·5
Repairs and maintenance	£167	£140
Miscellaneous supplies	£93	£105
Labour in operation	£298	£455

These figures relate to the electrical reversing mill of the Steel Company of Canada, and those for power consumption were obtained with the mill working much below its normal capacity.

H. F. Stratton (*Iron Age*, 1916, vol. 98, pp. 1166–1170) deals with the electric driving of rolling-mills with special reference to the troubles likely to arise with motors. The subject is discussed from several aspects, including the control of motors in parallel, the effect of faulty breaking, the number of the acceleration contacts advisable, controller features generally, the control of motors in series, and current characteristics.

Fly-Wheel for Rolling-Mill Engines.—F. Andrew (*Foundry Trade Journal*, March 1917, vol. 19, pp. 129–132) gives an illustrated description of a large fly-wheel for a rolling-mill engine.

Purchased Power for Rolling-Mills.—At the tenth annual meeting of the Association of Iron and Steel Electrical Engineers (*Iron Trade Review*, 1917, vol. 60, pp. 375–378) a paper was presented on " Central Station Power " for steelworks, the authors giving reasons why it is looked upon with favour by steelworks engineers.

Electric Cranes for Steelworks.—B. H. Reddy (*Iron Trade Review*, 1917, vol. 60, pp. 305–314) deals with problems of electric crane design and urges the construction of travelling cranes on practical lines. Important factors in design are discussed with considerable detail and simplified methods are suggested. The article is fully illustrated.

New Gun Shop.—A description is given (*Iron Trade Review*, 1917, vol. 60, p. 402) of the new gun shop of the Bethlehem Steel Company for the manufacture of the 16-inch 5-calibre guns designed by the United States Army and Navy for coast fortifications and for battleships.

Expanding Boring Tool.—An illustrated description has appeared (*Mechanical Engineer*, 1917, vol. 39, p. 75) of a novel design of expanding boring tool for use in the boring out of shafts and similar work, designed by Messrs. Vickers, Ltd., London, in conjunction with Mr. S. Robinson.

Milling Cutter.—An illustrated description has appeared (*Mechanical Engineer*, 1917, vol. 39, p. 266) of a design of milling cutter of the built-up type for machining metals at high speeds, the invention of Messrs. Watson, Billetop, Ferrier & Boyd, Newcastle-upon-Tyne.

Standardisation of Machine Tools.—C. G. Barth (*Iron Age*, 1916, vol. 98, pp. 1394–1397) gives a number of recommendations on the subject of standardisation of machine tools. The need for uniform conditions in regard to standards of speeds and feed series, standardised power for machine tools, tool posts, and lathe centres are emphasised, diagrams and mathematical data being given to show to what conditions such standards should conform.

FURTHER TREATMENT OF IRON AND STEEL.

Hardening and Tempering Furnaces.—A detailed illustrated description has appeared (*Mechancial Engineer*, 1917, vol. 39, p. 108) of a furnace for hardening and tempering steel invented by S. W. Brayshaw & Son, Manchester, and H. J. Yates. In this furnace the secondary air supply is heated solely by the waste gases after their useful effect in heating the furnace has been exhausted, and only a limited amount of primary air is admitted unmixed with the gas partially to support combustion and cause the gas to burn with a smoky or greasy flame, which will not have an oxidising effect. This construction, whilst heating the secondary air to a high temperature, has not any cooling effect upon the sides or bottom of the furnace.

Some details are given (*Journal of Industrial and Engineering Chemistry*, January 1917, vol. 9, p. 99) of gas furnaces recently installed for metal working by Messrs. Van Nuxen & Bonnasseau, Paris. Four furnaces consisting of Méker burners have been fitted in substitution for two burning oil. One of the new furnaces is for use in tempering tools, the other three are for the heating of steel bars to facilitate their further drawing. The latter range in diameter from $\frac{3}{4}$ inch to $4\frac{3}{4}$ inch and in length from 10 to 20 feet. They are supported on arms and heated to redness over a length of from 12 to 16 inches. The burners are supplied with a mixture of gas and compressed air, each furnace consuming 350 to 420 cubic feet per hour. The combustion of the gaseous mixture takes place against an inclined wall immediately over the furnace hearth, and it thus envelops the whole of the latter in a sheet of flame into which the bars are thrust. It is found that about 11,000 cubic feet of gas are sufficient for the treatment of some 50 tons of the steel bars and the results have proved satisfactory.

C. E. Richardson (*Journal of Industrial and Engineering Chemistry*, October 1916, vol. 8, pp. 911–914) describes, with illustrations, an artificial gas-fired furnace installation put down at the works of the Eddystone Ammunition Corporation, Pennsylvania, for the purpose of hardening and tempering (or drawing) 3-inch shells. The installation consists of three hardening furnaces and three tempering furnaces. One hardening and one tempering furnace are at present under construction and two each at present in operation. The furnaces are arranged in units—one hardening and one tempering furnace comprising a unit. Each unit is designed to turn out 5000 shells in a 20-

hour day. The full capacity of the installation (three units) would be 15,000 shells per 20-hour day.

A description has appeared (*Journal des Usines à Gaz*, August 5, 1916) of a gas furnace recently installed by a firm in Paris for the annealing of soft steel wire coils. The furnace consists of a masonry structure reinforced with external channel standards and fitted with counterpoised doors for the introduction and removal of the coils. The furnace is heated by five atmospheric burners, arranged along the length of the base, which yield a temperature of 800° C. and consume about 20 cubic metres per hour. The furnace is continuous in action, one coil being inserted on one side and at the same time another removed by the opposite door. On this system ten hours are required to anneal 75 coils, equivalent to 2½ kilogrammes of steel. The gas consumed per hour is thus 2·6 cubic metres, costing about 2s. In comparison with the coal furnace previously in use, it is found that the results are better, owing to the more exact regulation of the temperature, and that there is no production of brittleness from faulty heating. Moreover, the wire is found to be heated uniformly throughout its entire length. The soft steel wire of 5 millimetres diameter is annealed in coils, each weighing 35 kilogrammes.

R. Hackett (*Paper read before the North British Association of Gas Managers; Foundry Trade Journal*, November 1916, vol. 18, pp. 590–591) deals with the use of gas furnaces, especially as employed in the heat treatment of steel.

An illustrated description is given (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 639) of coke-fired regenerative muffle furnaces manufactured by the Richmond Gas Stove and Meter Company. An elevation and section are also given of a coal-fired continuous billet heating furnace by the same company.

Annealing Furnaces with Surface Combustion.—Two annealing furnaces, employing the surface combustion principle, are in operation at the Remington Arms Company, Eddystone, Pa. (*Iron Age*, 1916, vol. 98, pp. 636–637). The forgings can be treated without packing or other means for protection against possible oxidation. The furnaces were adopted for annealing rifle parts. They are of the car-bottom type, taking a charge of 20,000 to 40,000 lb. The annealing temperature is 845° C., and for a maximum weight charge 72,000 cubic feet is used by each furnace. Two charges can be turned out per furnace in twenty-four hours. Illustrations of the plant are given.

Oil Burner for Metal-Heating Furnaces.—A design of oil burner for use in conjunction with furnaces for the heat treatment of metals has been invented by the Manchester Furnaces, Ltd., Manchester (*Mechanical Engineer*, 1917, vol. 39, p. 135). The air supply, which is under a low pressure, is delivered through concentric passages, the central one of which contains the main air supply, whilst the outer

passage contains the supplementary or auxiliary air supply. The oil is delivered through a radially disposed pipe into the main air passage, the end of the tube being cut away at the burner side. At a short distance from the oil inlet, and at the end of the main air passage, is mounted a vane wheel, the vanes of which extend into the end of the annular supplementary air inlet passage. At the inlet side of the vane wheel is a conical part which directs the main air and the oil carried thereby into the vanes of the vane wheel. The rotation of the latter, due to the air flow, results, it is claimed, in a thorough atomisation of the oil and the mixture of the latter with both the main and the supplementary air. The oil-laden air passes into a combustion chamber in which it is ignited and burns. A suitable lighting aperture and a cleaning and inspection door are provided in the chamber.

Case-Hardening Furnace.—A descriptive illustration is given of a new type of case-hardening furnace supplied by the Monometer Manufacturing Company of Birmingham (*Engineer*, March 23, 1917, vol. 123, p. 276).

Case-Hardening of Iron.—A contribution to the study of the cementation of iron has been made by S. A. Feschtchenko-Tchopovsky (*Revue de la Société russe de Métallurgie*, 1914, vol. 1, pp. 245–310; *Revue de Métallurgie, Extraits*, 1915, vol. 12, pp. 518–522). Wood-charcoal from hard wood carbonised for four hours at 400° C. is the best material for cementation. The operations were carried out using carbon monoxide gas, and the cementation proceeded most rapidly at a temperature of 900° C. Additions of lithium carbonate, sodium carbonate, oxalate and acetate, potassium carbonate, tartrate, and chromate greatly increase the rate of carburisation when added to wood charcoal.

T. Baker (*Lecture delivered before the Rotherham Technical Institute Engineering Society; Mechanical Engineer*, 1917, vol. 39, pp. 134–135) deals with case-hardening, and considers in detail the selection of a suitable steel and the choice of a composition.

Exfoliation and Carbon Concentration in Case-Hardening of Steel.—E. P. Stenger (Hochstetter Prize Thesis, University of Cincinnati; *Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 425–433) points out that the most serious problem met with in the superficial cementation and hardening of machine parts is the phenomenon of exfoliation well known to all who have had to examine the fracture of case-hardened pieces after their failure in service. The cemented zones split or exfoliate from the core, and the distribution of the carbon in the cemented zone of the case-hardened material is shown to have an important bearing on such exfoliation, which is evidently caused by some internal strain being produced during case-hardening. Experiments were carried out with a view to throwing some light on the causes of this action, which have hitherto been somewhat obscure,

and it was found that the exfoliation was associated with the increase in volume caused by the hardening of steel. Indeed it may be said to be caused by the difference in the volume changes of the core and of the cemented zone which take place during the hardening of cemented steel. It was found possible to subject the stresses tending to produce exfoliation to analysis and hence to keep them below the safe limit by so designing the parts to be cemented that the case should have a thickness and carbon concentration compatible with the material used. In the design of machine parts most elaborate formulæ are used to counteract external stresses, but internal stresses are left to look after themselves. This neglect, although recognised, cannot yet be remedied, because the internal stresses are not yet thoroughly understood, and the data concerning them are not available. The evil effect of segregation in carbon is due probably to the same causes that produce exfoliation, the carbon itself being only indirectly the cause of the failures in such steel. Segregation is less noticed in nickel steel because the stresses produced by the volume changes are low, but it is not likely that the nickel really prevents carbon segregation but rather it obliterates the harmful effect of such segregations.

Case-Hardening Compound.—P. W. Brennan (*Foundry Trade Journal*, October 1916, p. 545) has patented the following as a case-hardening compound:

	Ounces.
Potassium cyanide	2
Sodium bicarbonate	1
Potassium bicarbonate	1
Bone-dust	½

the ingredients being powdered and thoroughly mixed. The iron or steel to be case-hardened is heated and covered with the mixture, after which it is again heated to a bright red and plunged into water.

Heat Treatment of Large Forgings.—Sir W. Beardmore (*Paper read before the Institution of Mechanical Engineers*, March 16, 1917) states that in the heat treatment of large forgings there are no metallurgical principles involved which do not apply with equal force to the heat treatment of small forgings. In carbon-steel forgings produced to meet a definite mechanical test specification the steel must possess the least crystalline growth or the smallest grain size, and the object of all heat treatment is to confer this condition on the forging before it leaves the steelworks. At any chosen temperature, the time the material is kept at its heat and the time taken to cool it down again to normal temperature have an all-important influence on the grain size, so that in large forgings all the difficulties of heat treatment are magnified. A limit is reached in the size of the forging beyond which a plain carbon steel cannot be used with safety, and the use of an alloy steel becomes imperative.

The slowness with which heavy masses of steel cool down results in large crystal grains at the centre of the mass, and, to avoid this, recourse is had to oil-quenching to hasten the cooling, while a subsequent reheating is generally necessary to remove the hardness introduced by the quenching operation. With small forgings a simple annealing will put the material into the condition which will give satisfactory and safe results, but for large forgings some form of heat treatment is very necessary. It is not sufficiently realised by engineers that in plain carbon steel the effect of oil-quenching is not uniform over the cross-section but diminishes from the outside surface. This effect is shown by micrographs relating to an oil-treated shaft, 18 inches diameter, of the following percentage composition: carbon, 0·18; manganese, 0·65; silicon, 0·10; sulphur, 0·048; phosphorus, 0·037. This was heated at 820° C. for two hours and cooled in oil. Tests of the outside skin and the centre gave the following results:

	Elastic Limit.	Ultimate Stress.	Elongation on 2 Inches.	Reduction of Area.
	Tons per Sq In.	Tons per Sq. In.	Per Cent.	Per Cent.
Outside	17·5	33·1	27·0	53·1
Centre	15·0	29·0	31·0	46·0

The effect of work is very important, and there is an intimate relation under practical conditions between the grain size and the amount of work during forging. For the very best results the ratio of the cross-section of the ingot and the largest cross-section of the forging should not be less than 3 : 1. Preferably it should be as great as possible, but for large sizes it is limited by the maximum size of ingot with which the presses can deal and sometimes by the shape of the forging itself. For an ingot 83 inches in diameter the maximum size of the forging should not exceed 48 inches for the best practice. For high tensile material (over 40 tons strength), where the factor of safety is limited owing to the special conditions under which the material has to be employed, it will generally be safer to use an alloy steel, since for the same tonnage a very much tougher material can be developed.

A very troublesome feature of large forgings which have been heat treated is distortion due to internal stresses, probably set up by quenching. On machining, especially on removing the outside, these stresses are partly relieved and distortion occurs. It is therefore advisable to rough-machine the forging after treatment and then re-anneal.

H. H. Ashdown (*Paper read before the Institution of Mechanical Engineers*, March 16, 1917) gives some general notes on the subject of heat treatment of large forgings. Micrographs are given to show the types of structure obtained in steels subjected to various heat treat-

ments, and instances from actual practice are quoted of forgings which had failed even before being put into service, and from which material was taken and brought into good condition by the correct treatment.

R. K. Bagnall-Wild and E. W. Birch (*Paper read before the Institution of Automobile Engineers; The Automobile Engineer*, May 1917, vol. 7, pp. 120–128) give instances of the effect of treatment in producing the necessary qualities in steel forgings, with special reference to forgings used in aeroplane and aeroplane engine construction. Some notes are given as to the practice to be followed with certain types of alloy steels in order to obtain the desired properties by different heat treatment, and a number of illustrations, micrographs, and sulphur prints are included.

An illustrated article has appeared (*Iron Trade Review*, 1917, vol. 60, pp. 365–368) on heat treatment of shrapnel forgings, and as an example of the important part played by that process, the methods of the Hofman plant of the Symington Machine Corporation at Rochester, N.Y., are described, where 75-millimetre Russian shrapnel are being made at a rate of over 15,000 a day. The heat-treating department in this plant has been developed to an unusual degree of efficiency, and has been largely responsible for a remarkably low percentage of rejections.

Manganese-Aluminium Castings and Forgings.—P. E. McKinney (*Paper read before the American Institute of Metals*, September 11, 1916) gives an account of the production of manganese-aluminium alloys, and shows their mechanical properties as influenced by mechanical and heat treatment.

Sandberg Process for Surface Hardening of Rails.—C. P. Sandberg (*Foundry Trade Journal*, October 1916, vol. 18, p. 548), in discussing the claims of his patent for a method of treating steel, states that the heat treatment of steel rails, using the usual methods of treating steel, has not been successful owing to the varying temperatures at which the rails leave the rolls, the great and varying speed at which they travel, the variation in weight, and therefore mass to be cooled. The inventor has found that if carbon steel, while at a temperature above the critical, is treated with an elastic fluid such as air or steam, or a very finely divided or atomised water or brine, or both elastic fluid and liquid together, delivered on the surface of the steel so as to cool it moderately rapidly, or quicker than it would cool normally, but not so swiftly as to produce a brittle or martensitic structure, the desired hard and tough sorbitic structure can be secured without double heating or reheating or the formation of fine cracks. The author avails himself of the heat existing in the rail after the completion of the rolling operation. While the rail is still above the critical temperature, steam or air, or a mixture of air and steam, is caused to impinge on the head of the rail for a time varying with the weight and

section and the temperature. The operation is so conducted that the rate and degree of cooling are such that when the cooled upper portion of the head is reheated by any heat retained in the upper part not yet cooled, or cooled more slowly, the hard and tough structure produced is retained and the upper part is of great hardness combined with toughness, the other portions of the section being practically unaffected. It is claimed that no reheating, before and after the rapid cooling, is necessary. The process is now being used for hardening the surface of worn tram-rails without removing them from the track.

The Vickers Surface-Hardening Process.—A description of the Vickers process of local surface hardening, which consists of applying momentarily to the surface of the part to be treated an intensely hot flame from any oxy-acetylene blowpipe is given (*Iron and Coal Trades Review*, January 1917, vol. 94, p. 5). The effect of this is to raise the surface of the object to a high temperature, it being then immediately quenched by the cold body of the metal beneath. The equipment is that usually provided for oxy-acetylene welding, but the temperature of the flame is higher, the increase being obtained by adjusting the flame as for welding and then increasing slightly the supply of oxygen. The body of the work must be kept as cool as possible, to insure that the quenching is sufficiently rapid. For small parts it is customary to immerse them in cold water. Bodies of large parts may be left to cool off by themselves, but where necessary a supply of cold water may be allowed to flow over the work. In both cases the actual surface to be hardened is not to be submerged in water unless it is desired to give only a very shallow depth of hardened crust. The process is being largely used for gear-tooth hardening. In calculating the cost of the process for the purpose of comparison with furnace-treated work, it must be remembered that—whereas for the latter process it is customary for the machining of the work to be carried out to approximate dimensions only, so that any distortion due to the heat treatment may be corrected by grinding and straightening—in the local surface-hardening process the work is machined to the finished dimensions, since no distortion is caused by the process.

Heat Treatment of Special Steels.—F. Giolitti and L. Sobrero (*Metallurgia Italiana*, February 1917, vol. 9, pp. 80-93) publish an important contribution to the study of heat treatment of special steels, in particular of the influence of tempering upon the hardness of various types of steel, forged and normalised by preliminary annealing.

Heat Treatment of Tool Steel.—The heat treatment of high-speed tool steels is dealt with by A. E. Bellis and T. W. Hardy (*Bulletin of the American Institute of Mining Engineers*, No. 121, 1917, pp. 61–68). The operation as performed on high-speed steel milling cutters is specially described, and photomicrographs are given of the proper structure

to be aimed at. The importance of carefully controlling the hardening temperature and varying it for the particular steel used cannot be overemphasised, and the practice of using one "high-speed temperature" for all tools is not to be commended. The benefit accruing from accurate heat treatment is out of all proportion to the time given to its study. They describe experiments on the hardening of five tool-steels of different composition.

Some interesting data on the cost of tempering steel tools electrically in an American automobile manufacturing plant have appeared (*Electrical World; Mechanical Engineer*, 1917, vol. 39, p. 328). The furnace was operated 98·5 hours in nineteen days, or 5·18 hours per day; in that time, 1978 high-speed steel tools, consisting of circular cutters, reamers, reamer blades, keyway cutters, taps, circular form tools, thread chasers, profile cutters, pointing tools, hollow mills, &c., were treated, at a cost of $26.6, with energy at 3 cents per kilowatt-hour. Adding the cost of renewing the carbon heating elements, $4.48, the total cost for the period becomes $31.11, or 1·57 cents per tool. During five runs, 352 lb. weight of tools were treated, at a cost of 2·33 cents per lb. These tools were treated in a Hoskins F.C.-204 furnace, with internal dimensions of 6½ inches by 5 inches by 11 inches, and maximum rating of 15 kilowatts; with temperatures of 2100° to 2300° F., the average demand is 9 kilowatts to 10 kilowatts. The accurate control of temperature and furnace atmosphere is a great advantage, because the better the tool the greater the efficiency of the machine. Improper temperature treatment may result in a difference of 30 to 70 per cent. in the life of the tool.

Heat Treatment of Chain Cables.—W. W. Webster and E. L. Patch (*Iron Age*, 1917, vol. 99, pp. 146-149) deal with the heat treatment of chain cables as elicited in the course of experiments to find a method of making a stronger product. The stiffness of an unannealed link is largely due to the overheated distorted structure in the welded end. Annealing relieves this condition by the process of recrystallisation, which practically wipes out all former structure and gives a finer and more normal grain size.

Manufacture of Large Chains.—F. G. Coburn (*Paper read before the American Society of Naval Architects and Marine Engineers; American Drop Forger*, February 1917, pp. 47-53) describes the development of processes for forging heavy chain links under uniform conditions and methods of building up long chains without interference. Tests of links welded by forging hammers showed the necessity of heat treatment of the welds, and after various attempts to heat-treat very low carbon material so as to improve the structure, the practice adopted was to air-quench the chain from a temperature slightly above the upper critical point. The equipment for forging large chains at the Boston Navy Yard is illustrated and described. Reference is also

made to an important paper by J. E. Otterson (*American Society of Naval Architects and Marine Engineers*, December 1913) on the manufacture of chain cables by hand and the attempts up to that date to produce chain by a power process.

Heat Treatment of Bolt Steel.—In a large steel plant in the United States (*Iron Trade Review*, 1917, vol. 60, p. 320) low-carbon steel was being used for most kinds of bolts, and a great deal of trouble had been experienced because of ragged threads. An investigation of the matter showed that the dies of the bolt cutter were in good condition, so that attention was directed to the steel. The steel was received in the annealed condition and was threaded according to the use of the bolts. It was thought that quenching the steel in fuel oil might produce a better threading material, and accordingly the threading stock was heated above its critical range and quenched in oil. In addition, the steel was drawn slightly when cold, although such an additional treatment cannot make much difference with low-carbon steel. Nevertheless, the steel so treated was much more satisfactory for threading stock; the threads were even and practically perfect. A number of experiments were tried on steel of varying carbon content, and the results showed that the stock threaded better if previously quenched in oil and then drawn back to various temperatures depending on the carbon content, than if threaded in the annealed state. The finer grain structure produced by the quenching treatment is more desirable than the coarse structure induced by annealing.

Determination of Annealing Temperature of Steel by the Action of Magnetic Flux.—R. B. Fehr (*Engineering Experiment Station, Pennsylvania*, Bulletin No. 18, 1916; *Journal of American Chemical Society*, 1917, vol. 39, pp. 82-84) has studied by magnetic methods the range of temperature in which the various steel heat-treating operations should be carried out. The magnetic critical point indicated without exception the proper annealing temperature for obtaining the correct mechanical properties. This point was in all cases within 30° above the critical temperature, and by careful temperature control a high-carbon steel could be given the same ductility as a low-carbon steel while retaining a higher elastic limit.

Electric Welding.—A general discussion on the pencil electrode method of welding was opened at the Annual Meeting of the American Society of Mechanical Engineers by E. A. Wildt (*Journal of the American Society of Mechanical Engineers*, 1917, vol. 39, pp. 46–47). In the pencil method only just enough heat is obtained to accomplish the joining of the two metals. A metal wire used as part of the circuit always forms one terminal and provides the welding metal. The pencil electrode and the forge method are alike in the fact that in neither is the metal heated beyond the necessary welding temperature. A high

temperature is prevented owing to the fact that as fast as the metal to be added to the weld becomes plastic the pencil must be advanced to the work to close up the spark gap, otherwise the current is interrupted. T. A. E. Armstrong (*Ibid.*) contributes to the discussion, pointing out that the superiority of electric welding over gas welding or fire welding is due to the extremely localised character of the heat generated by the electric arc, resulting in a smaller area of disturbance.

A committee of the Association of Railway Electric Engineers has published a report on the arc-welding process (*Power*, 1916, vol. 44, pp. 766–767). The amount of heat which can be applied depends very much on the size of the electrode, and it is also affected by the kind of wire used as electrode and by the character of the piece to be welded. The current and voltage that can be carried by electrodes of different sizes are as follows:

Electrode.	Size.	Amperes.	Voltage.
	Inches.		
Mild steel .	$\frac{1}{8}$	60–90	14–16
,, .	$\frac{5}{32}$	110–140	16–20
,, .	$\frac{3}{16}$	150–180	18–25
Carbon . .	$\frac{3}{4}$	250–350	35–50
,, . .	1	350–500	35–50

Three important changes occur in the metal during welding: (1) The effect of mechanical treatment is entirely eliminated over the area heated to a plastic or molten state. The metal thus affected becomes cast steel. (2) Unless the molten metal is protected by a slag covering, it is oxidised to a certain extent by the oxygen present in the atmosphere. This oxidation tends to make the metal cold short. (3) A large percentage of the impurities which may be present in the steel affected by the welding process before the operation is vaporised or oxidised and has disappeared after the operation. In bare wire welding, though the metal in the weld may have the same tensile strength as that of the original piece, it will be low in ductility but soft if the original metal did not contain over 0·35 per cent. carbon.

Three rules should be observed to get the best results in welding: (1) Hold a short arc; (2) use a low current; (3) work always on clean metal. Low-voltage direct current must be used.

Appliances for constant-current closed-circuit arc welding are illustrated and described (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 108–109). The arcs are operated in series, and it is claimed that current is greatly economised. Each arc is equipped with an automatic controller, which serves to maintain at all times the continuity of the circuit, so that no one arc can interfere with any other; it also controls the heat to be put into the metal to be welded. The arc can

be stopped at will without lengthening it, so that by this system it is impossible to draw a long arc and so burn the metal. Nor is the arc broken when the welding operation is stopped, but it is killed by placing a short circuit across it.

Arc Welding of Rail Joints.—E. A. Hoffmann (*Electric Railway Journal*, 1916, vol. 48, pp. 1244–1245) gives an account of experience in welding rail joints with the electric arc, and of the results of welded joints in service. The conditions for ensuring serviceable welds are stated.

Gas Burner for Welding Purposes.—An illustrated description is given (*Mechanical Engineer*, 1917, vol. 39, p. 325) of a design of gaseous fuel burner of the type employed in the welding of the seams of boiler flues and similar iron and steel bodies, the invention of Messrs. Alldays & Onions, Pneumatic Engineering Company, Ltd., Birmingham, and R. R. McGowan. The burner is of simple construction, and the parts are so arranged as to be easy of separation for cleaning or other purposes.

Oxy-Acetylene Welding.—A new method for the manufacture of light-gauge steel tubing is described (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 480). It consists in using an oxy-acetylene torch together with an automatic welding machine, which forms strip steel into cylindrical butted tubing, welds it, grinds off the burr, polishes the surface, cuts the tube in required lengths, and stacks them in stock piles, in an automatic continuous operation.

An illustrated description is given (*American Machinist*, 1917, vol. 46, p. 92) of an Hawaiian welding plant, most of the welding being performed with the Davis-Bournonville torch.

Comparison of Costs of Oxy-Hydrogen and Oxy-Acetylene Cutting.—W. P. Schuck (*Metallurgical and Chemical Engineering*, 1916, vol. 15, p. 218) states that the recent installation of plants producing oxygen by the electrolytic process has resulted in the production of a comparatively large amount of pure hydrogen as a by-product. The uses to which this hydrogen can be put are consequently of importance. For cutting steel plates up to about 5 inches thick acetylene can be used for the pre-heating flame, but heavier sections require the use of hydrogen. There are fewer makes of cutting torches adapted to the use of hydrogen with oxygen than those adapted to the use of acetylene with oxygen, due to the fact that hydrogen is less extensively used with oxygen, and most cutting torches are developed by makers of oxy-acetylene welding torches. Recently a combination cutting torch, that can be used with either oxy-hydrogen or oxy-acetylene by changing the tips, was developed, and a series of tests, summarised in Table I., showed the use of hydrogen to be much more economical:

TABLE I.

Thickness of Steel. Inches.	Cutting Speed. Feet per Hour.		Pressures at which Gases are Used.				Gas Consumption. Cubic Feet per Hour.			
	Oxy-hydro.	Oxy-acety.	Oxy.	Hydro.	Oxy.	Acety.	Oxy.	Hydro.	Oxy.	Acety.
¼	90	103	3	2	12	10	47	35	140	71
½	45	50	5	2	15	10	56	35	160	71
1	40	39	12	5	35	10	90	71	242	71
1½	33½	32	15	5	40	10	104	71	263	71
2	30	28	20	5	55	10	123	71	327	71

In terms of the amount of gas used per lineal foot of cut and the cost of cutting, these data present some very interesting facts, as shown by Table II.:

TABLE II.

Thickness of Steel.	Oxy-hydro.	Oxy-acety.	Oxy-acety. (Acet. ½*d*.).	Oxy-acety. Oxygen only.
Inches.	d.	d.	d.	d.
¼	0·8	2·15	1·70	1·35
½	1·85	4·80	3·90	3·20
1	3·55	8·25	7·10	6·20
1½	4·65	10·75	9·35	8·20
2	5·70	14·55	12·95	11·50

The cost of oxygen was taken at 1d. per cubic foot, hydrogen at ¾d. per cubic foot, and acetylene at 1⅛d. per cubic foot, and also at ½d. per cubic foot. The amount of oxygen required when using acetylene as the source of heat for pre-heating is so much greater than when using hydrogen, that it would be cheaper to use the oxy-hydrogen process at the prices named than to use oxy-acetylene, even if the acetylene were obtainable free of cost.

Shell Manufacture from Cast Steel.—E. F. Cone (*Iron Age*, 1917, vol. 99, pp. 41–44) notes the successful practice of shell-making from cast steel. The chief problems involved in this branch of industry are the elimination of pipes and segregation and the avoidance of surface defects. For the former the use of the hot top with the iron mould has been found the most successful, but even then, only when the height of the ingot is that necessary to afford one shell blank. When two shell blanks are cut from the same ingot there is a suggestion of secondary pipe in the lower shell blank. The avoidance of surface defects is largely bound up with the question of the mould and its wash.

Erosion of Guns.—H. Fay (*Bulletin of the American Institute of Mining Engineers*, No. 120, 1916, pp. 2237-2251) deals with the causes of gun erosion and of the hardening of the surface during use. Results obtained from the examination of a 12-inch gun are given. The greatest amount of wear and the maximum amount of hard surface layer were found in sections cut nearest to the powder chamber and at the beginning of the rifling. The area most eroded is freer from cracks than that in which less erosion is found. The three ordinarily accepted causes of hardening are exemplified in the metal of the gun by cementation, from the products of the combustion of the powder, particularly the carbon monoxide; heat treatment, by the surface heating of the metal at the temperature of combustion of the carbon, and its rapid cooling by abstraction within the mass, and the cold work or deformation from the hammering and gliding action of the projectile. That the hard surface is composed of martensitic material is proved by the fact that on tempering it passes over to characteristic troostite. The reason for a cold-worked metal being more susceptible to the sorbite→troostite→martensite formation when exposed to firing is not clear, but two explanations are given, of which the second is put forward as the more likely. This is that in a gun the original metal is sorbitic, and the iron carbide is therefore mostly in the free form, only a minimum amount being held in solid solution. When subjected to the pressure of cold work or the pressure of the explosion at a high temperature, solution may take place, each round of firing adding to the amount which goes into solution. This would lead naturally to the formation, first, of troostite, and when the solution is complete, of martensite. These steps are actually observed. The fact that steels high in nickel or manganese show the greatest amount of martensite formation, in ordinary erosion tests, tends to support this view.

Steel for Rifle Barrels.—C. B. Langstroth (*Iron Age*, 1917, vol. 99, pp. 189-190) points out that steel for rifle barrels should offer the maximum resistance to erosion and yet be fitted to meet machinery strength and requirements. Soft steel has now been largely superseded by nickel and manganese steels, while, to obtain uniform stock and to eliminate forging strains, the soft steel barrels are normalised by heating to 1625° F. for one hour, and then cooled in air. Experiments are advocated in the introduction of some new alloy or combination, with, it is suggested, higher silicon and lower manganese contents.

Steel Anchors for Ships.—E. F. Cone (*Iron Age*, 1916, vol. 98, pp. 813-815) notes the expansion of trade in the manufacture of steel anchors for merchant and battleships. Medium open-hearth steel is used, and in such cases the heat treatment is not much in doubt. When, however, it is sought to improve the static qualities by adding nickel or vanadium, the question of the right heat treatment becomes a more

vexed one. Proper and complete annealing is vital, and any error in that respect may imperil lives and property. Anchors of 20,000 lb. and upwards are now being made.

Manufacture of Electrolytic Iron Pipes.—At Grenoble, France, a firm is now manufacturing pipes of electrolytic iron up to 16.4 feet in length, 12-inch diameter, and $\frac{1}{8}$-inch thick (*Iron Trade Review*, 1917, vol. 60, p. 318). The metal as taken from the bath is hard and very brittle, but after a special and careful heat treatment is said to become of excellent quality and attain tensile strength of over 25 tons per square inch in any direction. It is claimed that these pipes compare favourably with cast-iron pipe. (See L. Guillet, "On Manufacture of Electrolytic Iron," *Journal of the Iron and Steel Institute*, 1914, No. II. p. 66).

Manufacture of Wire.—A. T. Adam (*Journal of the Society of Chemical Industry*, 1917, vol. 36, pp. 241-243) gives an historical account of the process of wire-drawing, and then describes modern practice in the manufacture of steel wire.

Steel-Lettering Stamps.—G. W. Klages (*Iron Trade Review*, 1917, vol. 60, p. 147) gives interesting evidence concerning the use of steel-lettering stamps when handled by expert workmen. He states that two carbon tool-steel, heat-treated stamps, made by J. H. Matthews and Co., Pittsburgh, have been in continuous use in his plant for nine years, and have been used by many of the workmen, so that each stamp has given at least 40,000 impressions on cold-rolled steel.

De-Tinning of Scrap Tinplate.—Some notes on the de-tinning of scrap tinplate are published (*Engineer*, May 18, 1917, vol. 123, pp. 442-443). The Goldschmidt process as practised at Essen is said to have consisted in placing tinplate in an atmosphere of gaseous chlorine, and on reaching a certain critical temperature chloride of tin is formed with the evolution of sufficient heat to keep the reaction going. At the temperature in question no action between iron and chlorine takes place. The value of the tin as tin chloride was higher than the value of smelted tin. The supply of tinplate scrap and the sales of the product were practically controlled entirely by the Goldschmidt Company.

PHYSICAL AND CHEMICAL PROPERTIES.

Problems in Physical Metallurgy.—G. K. Burgess (*Journal of the Franklin Institute*, July 1916, vol. 182, pp. 19–35) gives a brief sketch of certain problems in physical metallurgy which have been dealt with at the Bureau of Standards. A short account is presented of the preparation and properties of pure iron, of the application of the micro-pyrometer, and of the study of failures of material, in particular of steel rails and railway materials. A list of the investigations and tests of metals carried out at the Bureau is given.

Growth of Cast Iron.—H. C. H. Carpenter (*Proceedings of Staffordshire Iron and Steel Institute*, 1916–1917) presents some further notes on the growth of cast iron (see *Journal of the Iron and Steel Institute*, 1909, No. II. p. 29). The result of previous investigations showed that in the main the cause of the permanent swelling of grey cast irons on repeated heating is, in the majority of cases, a chemical change, viz., the expansive force of the oxidation of iron silicide, though there are, no doubt, cases in which the physical influence of the coefficient of expansion of dissolved gases in close grey irons makes itself felt, in creating a high internal pressure which causes the iron to expand. Consideration has hitherto been given to the swelling of grey irons at temperatures of between 700° C. and 950° C. There is, however, no doubt that given sufficient time these irons will swell and crack under the influence of high steam superheats. Such growths are smaller than those occurring at the higher temperatures, but are sufficiently large to cause trouble. A steam turbine casing recently was found to have grown 7 per cent. Another case was a high pressure steam-valve which had cracked and swollen badly in service, and was rendered useless. Investigation led to the conclusion that here also oxidation is the prime cause of growth, and that the steam forces its way in between the slits caused by the difference between the expansion of the graphite and that of the iron. The slits are gradually widened and oxides separate in the form of sheaths surrounding the graphite plates. Cracks develop and the specific gravity of the iron is lowered.

The chief agent producing swelling of grey irons on heating, whether at high or low temperatures, in air or furnace gases or superheated steam, is unquestionably silicon, present not as such but as dissolved iron silicide in the main bulk of the iron. But this silicide can exert no influence whatever in producing growth by separation as silica and

iron oxide, unless graphite is present which, on the heating of the iron, allows oxidising gases to penetrate into and gradually attack the metal chemically. Without graphite silicon is absolutely innocuous. A further conclusion is that a solution of the "growth" difficulty is only to be found by using a material which does not contain any free carbon, and further does not deposit it on repeated or prolonged heating. This rules out not only all the grey irons but many of the white irons. Moreover, the majority of the latter suffer from the disability of brittleness, as a result of which they almost invariably crack on heating. Therefore no grey cast iron and with few exceptions no white iron is really suitable. Mild or medium hard steels offer the best means of solving the difficulty. In fact cast steels containing from practically 0 to 2·5 per cent. of carbon show only a slight growth or shrinkage on repeated heatings, there being no free carbon in them, so that none is deposited on heating and the silicon is low. The conditions of growth are therefore absent.

Cooling Phenomena of Cast Iron.—T. Turner (*Paper read before the American Foundrymen's Association*, September 1916) demonstrates some of the scientific facts that underlie the behaviour of cast iron in cooling. Cast iron exhibits remarkable interruptions in its rate of contraction when cooling, in fact actual expansions take place at certain temperatures. The paper explains this phenomenon clearly. Among other things the following has been demonstrated: (1) White cast iron free from phosphorus has only one small expansion and one temperature arrest at about 670° C. (2) Grey cast iron free from phosphorus has two marked expansions and two temperature arrests at about 1135° and 695° C. (3) With an increase of silicon these arrest points occur at higher temperatures and nearer together. (4) In grey irons containing phosphorus there is an additional or third arrest at about 900° C.

R. Moldenke (*Iron Age*, 1916, vol. 98, p. 1459) discusses the thermophysics of cast iron and the influence of various factors on shrinkage. Solid metal is heavier than molten metal, or in other words, an equal weight of solid metal occupies less space than the liquid. This emphasises the seriousness of the shrinkage problem in cast iron as, unless feeding proceeds until the casting sets, spongy, porous, and weak castings will result.

Cast Iron for Engine Cylinders.—J. E. Hurst (*Paper read before the Manchester Association of Engineers; Engineer*, December 1916, vol. 122, p. 549) deals with the wearing of cast iron in engine cylinders, consideration being given to surface flaw phenomena; antifrictional properties; microstructure; hardness and wear and machining properties; growth; heat treatment of grey cast iron and effect of heat on engine pistons; and the chemical constitution of the metal.

Testing of Cast Iron.—F. J. Cook (*Paper read before the Staffordshire Iron and Steel Institute*, 1917) discusses the mechanical testing of

cast iron, drawing attention to the lack of uniformity in the tests called for, and the necessity for drawing up a standard series of rules for testing. The conditions of cooling and crystallisation and the effect of impurities require to be taken into account in determining methods of testing.

Inclusions in Steel.—A. McCance (*Journal of the West of Scotland Iron and Steel Institute*, 1916–17, vol. 24, pp. 55–68) has investigated the segregation of non-metallic impurities in steel. Sometimes during the machining of steel small holes are discovered filled with yellowish powder, generally known as sand or slag marks, and when examined under the microscope the sides of the hole are found to be coated with a similar non-metallic substance and the steel in the immediate neighbourhood is filled with globules and streaks all closely similar in colour. In a plate with a bad lamination on the surface a pocket of non-metallic impurity was found, which under the microscope had the typical appearance of the impurities generally termed manganese sulphide. A sulphur print of the section showed a very decided blackening, from which the inference would have been justified that the material was manganese sulphide. Analysis, however, showed it to be silicate of manganese and alumina with a little manganese sulphide in solution. The author traces the source of the formation and composition of such impurities. A sample of the scum which often floats on the surface of the steel as it rises was taken and analysed and was found to differ from the previous analysis only in the fact that ferrous oxide appeared to have replaced part of the manganese oxide. The scum had a darker appearance than the material taken from the plate but was distinguishable from slag by its fracture. If the scum is drawn under the stream of metal from the ladle it is projected with some force into the body of the ingot and broken into a thousand minute globules which may be retained in the steel when it solidifies. The surface of ladle pots and runners was noticed to have been fused to a brownish glass, a layer of which was chipped off and no doubt aided the formation of non-metallic segregates. Many non-metallic particles are of the order of 0·001 inch diameter, and their rate of rising in the steel is so slow that they mostly remain trapped in the steel. These are not so dangerous as particles of 0·01 inch diameter which will rise if they have the opportunity. To get rid of them, therefore, opportunities should be given for smaller particles to coalesce into aggregates large enough to rise to the surface, and for sufficient time to enable them to do so.

F. Giolitti and S. Zublena (*International Journal of Metallography*, 1915, vol. 7, pp. 35–82) have undertaken an investigation on the behaviour of slag enclosures in acid steel, the first series of their experiments dealing with enclosures in nickel steel and their effect on the structure. The steels used were acid open-hearth containing carbon, 0·38 per cent.; manganese, 0·60 per cent.; silicon, 0·22 per cent.;

phosphorus, 0·02 per cent.; nickel, 2·02 per cent.; also another similar steel containing 1·98 per cent. nickel. The slag enclosures were of the emulsified, light-grey type, lying between the ferrite borders and separate from the pearlite crystals. On heating small bars of the steel in an Heraeus furnace in an atmosphere of carbon monoxide for four hours at 1060° C. a slight decarburisation took place, and the enclosures were no longer separate from the pearlite. That is, the slag particles appeared to have lost their influence on the orientation of the ferrite. On heating the specimens to 1100° and 1190° the slag particles were no longer surrounded by ferrite. It is concluded from the experiment that the slag enclosures act as centres of crystallisation for the ferrite, and that this is not a direct physical effect but is really a chemical reaction due to the different rate of the oxidation and reduction processes and to the different conditions of unstable equilibrium between the two solid phases—the steel and the slag enclosures. The authors have established the fact that the activity of the slag with respect to the ferrite can be altered at will within very wide limits, and that its effect on the ferrite can be made to disappear and to reappear several times in the same specimen. The authors express the view that suitable thermal treatment can wholly, or at least partly, eliminate the injurious effects of slag enclosures.

F. Bondolfi (*Metallurgia Italiana*, March 1916, vol. 8, pp. 165 201) discusses various chemical and physical phenomena in steel, such as segregation; ghost-lines; the relations of iron, phosphorus, and carbon; iron manganese and carbon; iron sulphur and manganese; influence of oxygen and nitrogen; occlusion of gases; formation of blowholes; shrinkage and piping; and the production of sound ingots.

G. F. Comstock (*Bulletin of the American Institute of Mining Engineers*, No. 120, 1916, pp. 2103–2110) points out that the opinion commonly held by metallographists that all light grey inclusions seen under the microscope in polished sections of steel are manganese sulphide is apt to lead to generalisations not warranted by the actual facts. Iron oxide can assume a similar appearance and is apt to be confused with true sulphide inclusions. Photomicrographs illustrating this danger are given. The only real test described in the standard text-books for distinguishing between oxide and sulphide inclusions is to heat the polished sample in a current of carefully purified hydrogen, but this is too complicated a method and requires too much preparation and practice to commend itself for ordinary purposes, while neither etching with weak organic acids nor watching the bubbles resulting from the application of sulphuric acid was found to yield satisfactory results. Boiling alkaline sodium picrate, which is used to darken cementite, was, on the other hand, found to attack the sulphide inclusions, leaving black spots instead of the light-grey spots seen before etching, while the oxide inclusions were found to be absolutely un-

attacked, and the use of this reagent is advocated in order to distinguish between the two, the mode of applying it so as to get the most satisfactory results being explained in detail. A number of photomicrographs illustrate the results obtained.

Influence of Carbon on Strength and Structure of Mild Steel.—W. E. Dalby (*Paper read before the Institution of Naval Architects*, March 28, 1917) shows that the strength of steel of normal composition and having the normal pearlitic structure is dependent on the pearlite present, and gives a straight line when plotted against the carbon percentage. The process of solidification of steel and the phenomena influencing the growth of the crystals are considered, and some excellent micrographs illustrate the internal structure of steel. Steel containing about 0·9 per cent. of carbon is built of blocks of pearlite and nothing else. The pearlite is a conglomerate constructed of alternating sheets of iron and cementite, packed closely together 60,000 to the inch, and these packed sheets are bent into the shapes which suggest that the final forms as seen under the microscope have been developed against a complicated play of internal molecular forces.

Influence of Quenching Temperature and Time of Tempering on Properties of Steel.—H. M. Howe and A. G. Levy (*Proceedings of the American Society for Testing Materials*, 1916, vol. 16, Part II., pp. 7–50) present and explain results showing the influence of the quenching temperature, and of the temperature and time of tempering, on the hardness and microstructure of quenched (hardened) steel containing 0·92 per cent. of carbon. The paper also records preliminary studies of the Shore scleroscope test. The composition of the material was carbon, 0·92 per cent.; silicon, 0·14 per cent.; manganese, 0·123 per cent.; phosphorus, 0·009 per cent.; sulphur, 0·011 per cent. The following definitions are given by the authors:

To harden steel is to cool it rapidly, for instance by quenching it in water from above the bottom of the transformation range, commonly called the critical range, that is, from above the recalescence, or A1.

To temper hardened steel is to reheat it to any temperature below A1. The authors do not try to set the limit between tempering and annealing.

The tempering temperature is that to which hardened steel is thus reheated.

The tempering time is that during which the steel is held at the tempering temperature.

A summary of the paper is given as follows: If eutectoid steel is heated to 800° C. and quenched either immediately or after slow cooling to one or another of a descending series of temperatures the volume of the quenched steel decreases progressively as the quenching temperature sinks towards the recalescence or Ar1, showing that the

arrest of the transformation by the quenching becomes progressively less complete, whereas little change in the resultant hardness occurs. As the quenching temperature is lowered from above to below Ar1 the decrease of volume is suddenly and greatly exaggerated and a sudden loss of hardness occurs. Further lowering of the quenching temperature does not affect the volume, showing that the transformation completes itself on passing Ar1; but the hardness decreases progressively, in the authors' opinion, because of the increased opportunity for the coalescence of the cementite and ferrite respectively.

In Part II. the rate of decrease of the hardness of hardened eutectoid steel, as the time and temperature of tempering increase, is shown graphically. The effect for temperatures above 400° C. is attributed to coalescence, and to this also may be due an important part of the time effect for lower temperatures. The microstructural changes caused by variations in quenching temperature and by tempering are shown by micrographs. The oxide colours found in the tempering cracks are deeper the longer the tempering at a given temperature.

The observed Shore hardness increases with the thickness of the specimen and with the distance from its edge within limits, and also on superposing well-fitting specimens, but not when many specimens are set on one another probably because of the cumulative effect of surface inaccuracies. What thickness and distance from the edge are required for true readings has not been ascertained, but neither a thickness of 0·62 inch in hardened eutectoid steel nor a distance of 0·078 inch from the edge in tempered steel of about 0·20 per cent. of carbon suffices. On repeating the Shore test in the very same spot the observed hardness at first increases rapidly and becomes about tripled, so that that of dead soft ferrite equals that of hardened eutectoid steel. But after numerous repetitions the observed hardness drops abruptly often apparently to zero, to recover to or above the previous maximum. This recovery may be spread out over as many as twelve successive impacts. The Shore hardness of such a conglomerate as unhardened eutectoid steel may be extremely uniform or it may vary greatly with a surprising tendency to be concentrated on two numbers about midway in the range and to avoid numbers intermediate between these two.

Influence on Mechanical Properties of Time of Heating prior to Quenching.—A. Portevin (*Revue de Métallurgie*, 1916, vol. 13, pp. 9–78) has made experiments as to the influence on the mechanica properties of the time of heating prior to quenching, both the time the temperature is rising and the time it remains constant being made the subject of special study.

Time Effect in Reheating Hardened Steel.—C. R. Hayward and S. S. Raymond (*Bulletin of the American Institute of Mining Engineers,*

No. 122, 1917, pp. 277–285) describe their investigations on the effect of time, as a guide to the heat treatment of steel. A number of specimens were heated to 800° C., quenched at this temperature, and reheated in sets of three, for 15 minutes, 30 minutes, 1 hour, 2 hours, and 4 hours at 300°, 400°, 500°, and 600° C., after which they were mechanically tested both for tensile strength and for hardness. The results are summarised in tables and represented graphically in diagrams.

Influence of Temperature on Physical Properties of Metals.—In a previous notice of an investigation by P. Ludwik (*Zeitschrift des Vereines Deutscher Ingenieure,* 1915, vol. 59, p. 657) mention was omitted of the discovery that the physical properties of metals when plotted against fractions of their absolute melting temperatures almost coincide. For example, if the melting temperature of any metal be 1000° C., then the absolute melting temperature is 1255° C., and the metal at one-half its absolute temperature has practically the same tensile strength as any other metal at half its own absolute temperature. Alloys form exception to the rule, which holds good only for practically pure metals, over a wide range.

Influence of Temperature on Bending Resistance of Steel Wire.—Lautz (*Zeitschrift des Vereines Deutscher Ingenieure,* September 1916, vol. 60, pp. 785–788) gives results of alternate bending tests of wires at various temperatures. The resistance of wire to fracture by alternate bending remains fairly constant up to 120° C. Between 120° and 220° C. the resistance increases rapidly, and above the latter temperature falls very suddenly. The maximum values are about double those obtained at ordinary temperatures. In annealed wires the maximum is very pronounced.

Hardness Tests.—The committee appointed by the Institution of Mechanical Engineers to investigate hardness tests, has presented its report upon the experiments made at the National Physical Laboratory by T. E. Stanton and R. G. Batson (*Proceedings of the Institution of Mechanical Engineers,* October–December 1916, pp. 677–723). A description of some of the better known tests which have been devised for obtaining the relative resistance of materials to surface deformation, to all of which the term "hardness tests" is sometimes loosely applied, is given in an Appendix. A preliminary examination of these methods shows that each of them falls into one or the other of two distinct categories. These are: (1) abrasion or scratch tests; (2) indentation tests.

The general results of the tests are as follows:

1. *Ratio of Brinell Hardness Number to Scleroscope Number.*—

The results of these determinations are in approximate agreement with the general assumption that the Brinell hardness number divided by 6 is approximately equal to the scleroscope number. According to the evidence of the present tests, the ratio of the Brinell hardness number appears to increase gradually from 5·5 for very soft material to about 8 for materials of over 700 on the Brinell scale.

2. *The Preservation of the Nature of the Surface during the Progress of the Test.*—The characteristic which distinguishes the sliding abrasion test from the rolling abrasion test is that the former does not cause any perceptible hardening of the surface under wear as the test proceeds; that is, the test is not made on deformed material, but on material in the state in which it existed before the test.

3. *The Relation between the Resistance to Sliding Abrasion and the Brinell Hardness Number.*—In order to express in a concise form the extreme variations in resistance to wear corresponding to any given Brinell hardness number, which have been found in the miscellaneous selection of materials tested for the present investigation, the figures given in the following table have been abstracted from the results :

Brinell No.	High Resistance to Sliding Abrasion.		Low Resistance to Sliding Abrasion.	
	Test No.	Resistance to Abrasion.	Test No.	Resistance to Abrasion.
165–175	22 (175)	63	29 (165)	36
190–206	20 (206)	80	19 (190)	38
226–228	26 (226)	67	34 (228)	7
228–235	14 (235)	91	8 (228)	26
255–271	25 (271)	200	24 (255)	4 to 10
330–332	16 (330)	500	28 (332)	24
346–364	11 (346)	200	23 (364)	36

These give the maximum and minimum values of the resistance to sliding abrasion for materials whose Brinell hardness number is approximately the same. The special steels are responsible for the enormous variation in resistance to sliding abrasion, given in the table; in the case of ordinary carbon steels the fluctuation is much less. As regards the latter steels, it may be said that a high Brinell hardness number generally indicates a high resistance to sliding abrasion, but there are exceptions to this rule.

It is clear that the Brinell hardness numbers of a miscellaneous selection of steel are not a safe guide in predicting their relative resistances to wear. This result is in general agreement with those obtained by Robin, Nusbaumer, and Saniter.

In an Appendix Sir Robert Hadfield sums up the situation as to hardness as follows :

Hardness as generally understood is a loose term, not representing any specific property, but "resistance to deformation."

No single value can therefore be assigned to the hardness of the material in this general sense. It can only be expressed by a complete stress-strain curve.

The "natural hardness" can be measured, and is the "yield-point stress."

There seems to be no satisfactory method of determining "deformation hardness." Scratch methods enable comparisons to be made of this more or less definite property, but do not give a numerical value.

Definition of Hardness.—A further Appendix by A. E. H. Tutton defines the hardness of a solid substance as the resistance offered by a smooth surface of the substance to abrasion. It is intimately connected with cohesion. If the solid substance is crystallised, the hardness varies slightly with the direction within the crystal, as cohesion in a crystal is in general dissimilar in different directions; thus hardness is always lower along a direction of cleavage than along the direction perpendicular thereto.

F. Ricolfi (*Metallurgia Italiana*, December 1916, vol. 8, pp. 690–699) discusses the application of the Brinell method of hardness testing for controlling the manufacture and treatment of projectiles.

Effect of Cold Twisting on Properties of Mild Steel Bars.—P. B. Whitney and G. K. Dohner (*Journal of Engineering, University of Colorado*, 1916, vol. 12, pp. 48–55) have carried out a series of tests to determine the effect of twisting upon the properties of steel.

The material used had the following analysis: Carbon, 0·22 per cent.; sulphur, 0·039 per cent.; manganese, 0·34 per cent.; and phosphorus, 0·032 per cent. The bars tested were ⅜-inch, ½-inch, and ⅝-inch plain square bars. They were 30 feet in length and were so cut that the whole series of tests could be performed on specimens cut from a single bar, thus assuring uniformity of composition and treatment. The specimens were 16 inches, 20 inches, and 18 inches long. Half of the specimens were tested unannealed and half annealed.

The results show that the elastic limit is increased by amounts varying from 10·5 per cent. for ⅜-inch bars with one twist in 12 t (t= size of bar) to 80·45 per cent. for ⅝-inch bars with three and one-quarter twists in 12 t. There was no perceptible yield point in any of the twisted bars, although in the plain bars it was very pronounced. The ultimate strength was increased by amounts varying from 2·27 per cent. for ⅜-inch bars with one twist to 12 t, to 37·86 per cent. for one ½-inch bar with three and one-half twists in 12 t. Ductility is indicated by the percentage ultimate elongation and the percentage reduction in area. The percentage elongation for ¾-inch bars was reduced from 25·37 per cent. for plain bars to 3·25 per cent. for bars

with four twists in 12 t. For $\frac{1}{2}$-inch bars the reduction was from 28·7 per cent. for plain bars to 0·87 per cent. for bars with four and one-half twists in 12 t. For $\frac{5}{8}$-inch bars the reduction was from 28·5 per cent. for plain bars to 3·75 per cent. for bars with three and one-quarter turns in 12 t

The percentage reduction in area was reduced from 56·0 per cent. for plain bars to 3·7 per cent. for bars with three and one-quarter turns in 12 t for $\frac{5}{8}$-inch bars.

It was found that as soon as a permanent set has been created by torsion there is a noticeable increase in the ultimate tensile strength and elastic limit, but a limit is reached in the number of turns, beyond which the tensile strength is reduced by further twisting.

Torsional Hysteresis of Mild Steel.—J. J. Guest and F. C. Lea (*Paper read before the Royal Society*, December 7, 1916) show by experimental means that when mild steel is subjected to a torsional reversal of stress the material does not follow Hooke's law, and that there is a distinct stress-strain hysteresis loop even for comparatively small ranges.

Alternating Stress Test of Steel.—W. C. Popplewell (*Engineering Review*, October 1916, vol. 30, pp. 120–122) reviews briefly previous work in testing steel by alternating stresses, and describes three series of experiments carried out by himself. An attempt is made to predict the limited stress for an unlimited number of direct reversals by the Bauschinger method of slow reversals. The second set of experiments comprised the rotating beam tests. The third consisted of experiments in reversals of direct stress. The results are plotted in curves.

Elastic Limit of Open-Hearth Steel.—N. T. Belaiew and N. T. Goudsow (*Revue de Métallurgie*, 1916, vol. 13, pp. 116–148) have carried out experiments on the elastic limit of acid open-hearth steel subjected to various heat treatments.

Testing of Steel.—H. Brearley (*Paper read before the Manchester Association of Engineers*, March 24, 1917; *Mechanical Engineer*, 1917, vol. 39, pp. 256–259) gives the results of experiments carried out on the testing of steel, that is, as to its hardness, toughness, and elasticity. He suggests that (1) inspection should start at least as far back as the ingot; (2) a sample taken from an ingot discard might give the same analysis and the same tensile test as a sample taken from any other chosen part; (3) with correct analysis and tensile tests there might be associated either (*a*) unreliable (brittle) material, or (*b*) defective material; (4) ingot defects are relatively important,

according to the purpose for which the steel is used, and the same kind of ingot defect may be at one time fatal and at another time actually beneficial; (5) any amount of ingot discard is justifiable which leaves the remaining part better fitted for its purpose.

Testing Ductility of Sheets and Wire.—A description is given of the Erichsen method of testing the quality of ductile sheets and wire with a diagram of curves showing the relation between the thickness and the depth of dishing of good metal sheets. Cartridge strips and sheets can be tested by the Erichsen method by means of special tools inserted in the standard Erichsen machine (*American Drop Forger*, March 1917, pp. 89–93).

Tests on Fish Bolts.—E. Stimson (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 547) has published results of tests with fish bolts and spanners used by platelayers on the Baltimore and Ohio Railroad. The object of the tests is to show the relation between the loads on the bolts when drawn up tight with various length spanners and the elastic limit of the bolts. The averages of a series of tests with carbon steel bolts show the loads pulled with 30-inch and 36-inch spanners to be well within the elastic limit of the bolt, while the load pulled with the 42-inch spanner exceeds the elastic limit.

Brittleness Produced in Steel Springs by Electroplating.—M. De K. Thompson and C. N. Richardson (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 83–84) have investigated the causes producing brittleness in steel springs when plated by placing in a hot copper cyanide solution. No explanation of the phenomenon could be found, but it was observed that a cathode of spring steel becomes brittle when the hot electrolyte is either sodium cuprocyanide, or simply sodium cyanide. The effect is more pronounced with the latter electrolyte. The brittleness is produced whether the cathode is coiled or straight, but the carbon content and structure of the steel are not altered. Used as an anode no brittleness is produced in the steel. Annealed steel and also brass and phosphor bronze are not affected at all.

Brittle Effect of Nitrogen in Iron and Steel.—It is pointed out (*Iron Trade Review*, 1917, vol. 60, p. 252) that nitrogen induces brittleness in both iron and steel in a manner as yet not clearly understood. Bessemer steel is more brittle than open-hearth steel of similar analysis, regardless of the subsequent working and heat treatment. This is supposed to be caused by the large volume of air blown into the converter in the process of manufacture of the Bessemer product, thereby

exposing the metal to the nitrogen therein. In order to incorporate nitrogen into iron or steel for the purpose of experiment, a convenient method is to expose the test-piece to the action of ammonia gas (NH_3) at high temperature. Iron and steel begin to take up nitrogen at about 400° C.; the action is most marked between 600° C. and 700° C., and ceases at about 800° C. With high nitrogen content, that is, say, up to 7 per cent., the metal so contaminated can be broken in the fingers.

Production of Pure Iron.—What is claimed to be a new method of producing pure iron has been discovered by T. Yensen (*Foundry Trade Journal*, September 1916, vol. 18, p. 491) during an investigation of the magnetic properties of iron and iron alloys. The method used consisted of melting electrolytically refined iron in a vacuum, thus reducing the impurities far below any point that had been reached by previous investigators. The maximum permeability of the vacuum-fused iron—that is, measure of ease with which it can be magnetised—was found to be two or three times higher than for the best magnetic iron or iron alloy previously produced. A practical result of the investigation is that, if it should turn out to be commercially profitable, the amount of material needed for electrical machinery, such as transformers, would be reduced by half, and the losses that occur continuously as long as the machine is in operation would be greatly minimised.

Alloy Steels.—An account is given (*Iron Trade Review*, 1917, vol. 60, pp. 73–84) of the manufacture on a large scale of alloy steels by the United Steel Company, Canton. The company manufactures electric and open-hearth alloy steels, including chrome-vanadium, chrome-nickel, plain nickel steel (up to 5 per cent. nickel), chrome-carbon, tungsten steel for magnets, and chrome-silico-manganese steel.

Nickel-Chromium Steel.—A report on the manufacture and use of nickel-chromium steel has recently been published (*Iron and Coal Trades Review*, October 1916, vol. 93, p. 480). Tables showing the composition and properties of nickel-chromium steels before and after heat treatment are given (p. 404).

Chrome-nickel steel rails having 2 per cent. of nickel and 0·7 per cent. of chromium have been tried on several American railways, but with unsatisfactory results. They resisted wear well, but broke badly in both directions, so that they were considered unsafe, and were removed. They were made by the Bessemer process, and were not heat treated.

Castings of Nickel-Chromium Steel.—Castings made of chrome-nickel steel may be used in the annealed or heat-treated conditions.

TABLE I.—*Composition and Properties of Nickel-Chromium Steel before Heat Treatment.*

Sample No.	Composition.							Tensile Properties.					Remarks.
	C.	Mn.	Si.	S.	P.	Ni.	Cr.	Tensile Strength.	Elastic Limit.	Contraction of Area.	Elongation on 2 In.	Ball Hardness.	
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Lbs.	Lbs.	Per Cent.	Per Cent.		
1	0·55	0·41	0·22	0·03	0·02	1·53	1·14	96,000	75,000	66	31	185	Annealed.
2	0·18	0·27	0·05	0·04	0·02	1·28	1·59	72,000	51,000	71	37	134	,,
3	0·15	0·34	0·13	0·02	0·01	1·28	0·37	59,000	42,000	64	38	115	,,
4	0·29	0·42	0·07	0·06	0·02	3·86	1·48	...	...	...	...	...	Natural.
5	0·25	0·32	0·10	0·03	0·02	1·45	1·20	96,500	81,500	68	25	...	Test-piece.
6	0·25	0·32	0·10	0·03	0·02	1·45	1·20	97,100	80,900	49	...	...	Eyebar 21 ft. long.

TABLE II.—*Composition and Properties of Nickel-Chromium Steel in Heat-treated Condition.*

Sample No.	Composition.							Tensile Properties.					Heat Treatment.	
	C.	Mn.	Si.	S.	P.	Ni.	Cr.	Tensile Strength.	Elastic Limit.	Contraction of Area.	Elongation on 2 In.	Ball Hardness.	Temperature at which Steel was Quenched in Water.	Temperature at which Temper was Drawn in Air
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Lbs.	Lbs.	Per Cent.	Per Cent.		°C.	°C.
1	0·40	0·74	0·24	0·03	0·02	3·45	1·20	187,000	175,000	43	10	352	830	371
2	0·36	0·53	0·11	0·04	0·01	1·55	0·70	145,000	125,000	65	20	233	830	566
3	0·21	0·41	0·22	0·03	0·02	3·52	1·11	110,000	75,000	66	24	215	830	682
4	0·48	0·44	0·16	0·01	0·01	2·02	0·98	212,000	186,000	46	10	445	843	427
5	0·48	0·44	0·16	0·01	0·01	2·02	0·98	140,000	120,000	61	18	287	843	649
6	0·38	0·28	0·27	0·02	0·01	3·01	0·65	114,000	90,000	69	25	266	843	649

"Invar" Metal.—C. H. Guillaume (*Comptes Rendus*, 1916, vol. 163, pp. 654–658; *Journal of the Society of Chemical Industry*, 1917, vol. 36, p. 34) has studied the modifications in the dilatability of invar (nickel steel containing: Carbon, 0·5 per cent.; manganese, 0·5 per cent.; nickel, 36 per cent.), produced by mechanical and thermal treatment. For commercial uses, "invar" is usually rolled at a cherry-red heat and cooled in air. The present investigation was made to determine the effects of annealing, quenching, and cold working on the dilatability of the alloy as ordinarily supplied. The coefficient of expansion was increased by annealing for several hours at 900° C. and cooling in air or in the furnace, and decreased by quenching in water, the range of variation from these causes being $1{\cdot}18 \times 10^{-6}$. By cold drawing the annealed or quenched alloy, the dilatability was rapidly decreased, the combined effects of the thermal and mechanical treatments being to reduce the original coefficient of expansion by $2{\cdot}18 \times 10^{-6}$. The dilatabilities of quenched rods and cold-drawn wires, already $0{\cdot}49 \times 10^{-6}$ and $1{\cdot}50 \times 10^{-6}$ below that of the alloy as commercially supplied, were increased by $0{\cdot}42 \times 10^{-6}$ and $0{\cdot}80 \times 10^{-6}$ respectively, by prolonged heating at temperatures up to 250° C., whereas the dilatability of the alloy in the "natural" (as supplied) or annealed condition was scarcely affected by this treatment. From the results obtained it is concluded that the effect of cold drawing on the dilatability of commercial invar is practically neutralised, and the alloy is stabilised as far as geodetic requirements are concerned, by prolonged heating at 100° C.

Alloys of Chromium-Copper-Nickel.—D. F. McFarland and O. E. Harder (*University of Illinois Bulletin*, No. 93, 1916, vol. 14, pp. 5–57) present a preliminary study of chromium-copper-nickel alloys. The composition is given of sixty-six alloys prepared for the experiments, and their physical and mechanical properties, including hardness and specific gravity, were ascertained, the results being discussed. Corrosion tests were also made, and the losses in weight are recorded for all the alloys after exposure for definite periods to nitric acid, hydrochloric acid, sulphuric acid, sodium hydroxide, ammonium hydroxide, sodium chloride, and fatty acids. A number of photomicrographs accompany the report.

The conclusion is confirmed that chromium and nickel form a series of solid solutions in the alloys containing from 100 to 50 per cent. of nickel. Chromium and nickel form a eutectic which contains about 42 per cent. of nickel. The corrosion tests show that the amount of loss in the different reagents is not proportional to the strengths of the different acids or bases. No definite relation could be established between the relative electromotive forces and corrosion losses.

Composition of High-Speed Alloys.—A substitute for high-speed steel for tools has recently been patented (*Foundry Trade Journal*,

December 1916, vol. 18, p. 647) and is composed of ferro-chrome (containing about 70 per cent. chromium and 4 to 6 per cent. carbon) 8 parts, nickel 21 parts, silicon 1·7 parts, aluminium 2·5 parts by weight. The base alloy of nickel, chromium, and silicon is first melted, and the aluminium, ranging from 3 to 20 per cent., according to the hardness required, is then added. The molten alloy is cast into tools, which are ready for use, after grinding, without any additional heat treatment. Metals such as tungsten, vanadium, &c., in proportions up to about 1 per cent., may be added to the base alloy, and the nickel may be wholly or partially replaced by cobalt.

Composition and Properties of Nichrome.—A recent United States patent (*Mechanical Engineer*, 1917, vol. 39, p. 127) relates to nichrome, which it is claimed will withstand temperatures up to 550° C. without corroding, pitting, or oxidising. The metal is composed of 60 per cent. nickel, 26 per cent. iron, 12 per cent. chromium, and 1·5 per cent. manganese, and if substantially carbon free, under 0·40 per cent., can be machined, rolled, or forged. The alloy requires a high melting heat, but can be cast in the ordinary manner. It is suitable for incorporation into moulds for die-casting, valves and valve seats for internal-combustion engines, crucibles, outer castings, annealing boxes, case-hardening or carburising boxes, and other apparatus. Manganese content is not essential. The alloy is said to be strong and durable and resistant to sulphuric and other acids.

Influence of Uranium in Tool Steel.—Johnson (*Paper read before the American Chemical Society*, September 1916) discusses the value of uranium in tool steel. While 0·20 per cent. of uranium is considered or claimed generally to confer the same efficiency on tool steel as 12 per cent. of tungsten, it was found, on examination and use of such steels, that uranium steel is not as efficient. Also great difficulty was experienced in getting uranium into the steel; it seems to have a decided affinity for oxygen, and may be regarded as having a stronger attraction for oxygen than any other element. Uranium steel, containing about 0·40 per cent. carbon, 0·30 to 0·40 per cent. manganese, and about 0·30 per cent. uranium, was very poor and exceedingly red short.

The effect of the alloy uranium on high-speed steel is shown by the results of tests of uranium high-speed steel in comparison with the ordinary high-speed steel given in the following table (*Foundry Trade Journal*, October 1916, vol. 18, p. 534). The tests were made by the Standard Chemical Company, U.S.A., at a number of works in the Pittsburgh district. The tools marked A, B, C, and D are regular high-speed steel tools. Those marked U are uranium high-speed steel tools.

Material Cut and Tool.	Feed. Inches.	Speed f.p.m.	Cut. Inches.	Remarks.
Loco crankpin:				
U	$\frac{1}{16}$	74	$\frac{5}{8}$	Ran 12 inches.
A	,,	74	,,	Ran 2 ,,
U	,,	64	,,	Ran 8 ,,
A	,,	64	,,	Ran 2 ,,
U	,,	75	$\frac{1}{4}$	Went 14 inches. On second lap went 3 inches.
0·5 per cent. carbon 12-inch shaft:				
B	,,	75	,,	Went 4 inches.
D	,,	75	,,	Went 1 inch.
8-inch shaft 7 ft. 5 in. long:				
U	,,	51	$\frac{5}{8}$	Went over twice. Cut changed to $\frac{3}{8}$ inch on second turn.
C	,,	35	,,	Did not go 1 inch.
6-inch shaft:				
U	$\frac{1}{32}$	75	,,	Ran 18 inches.
U	,,	75	,,	Ran 13 inches. Speed increased to 90 f.p.m. and ran 11 inches. Tool still good.

Cerium Pyrophoric Alloy.—It is stated (*Foundry Trade Journal*, October 1916, vol. 18, p. 531) that the pyrophoric metal used on cigar-lighters and for igniters in miners' lamps might be considered as an alloy steel, as it consists substantially of 30 per cent. of iron with 70 per cent. of cerium. It was patented by Welsbach, whose name is identified with the Welsbach light. The striker is of the grade of hardened file steel with about 1·50 per cent. carbon. The detached particles of the cerium-iron alloy take fire in the air, ignition being quickened, no doubt, by the heat generated on the impact of the striker.

Bibliography of Alloys.—C. Estes (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 273–282) gives a bibliography of binary, ternary, and quaternary alloys whose equilibria have been investigated. The references are arranged on a new plan, alphabetically in correspondence with the atomic names of the elements concerned. A chart is added, showing the binary systems investigated.

Steels for Aeroplane Construction.—G. A. Richardson (*Paper read before the Aeronautical Society of America; Mechanical Engineer*, 1917, vol. 39, pp. 300–301) discusses steels suited to aeronautical purposes, dividing his subject into—(*a*) The requirements of structural parts and members, under which heading would come the consideration of stay wires, struts, and body parts, &c. (*b*) Power plants and transmission parts. (*c*) Protective armour for military planes. (*d*) Aeronautical instruments and miscellaneous equipment. His general conclusions are: (1) That the use for which the machine is intended will play an important part in determining the kinds of steel. (2) That

the design should precede the recommendation as to the steel used. (3) That in developing the use of special steels a great deal more experimental work will have to be done, and that standardisation of practice will be an absolute necessity if costs are to be reduced to a reasonable figure. Where cold drawing or cold rolling is involved the cost of dies and rolls is too great to admit of meeting the ideas of every individual designer.

W. S. Doxsey (*Iron Trade Review*, 1917, vol. 60, pp. 97–100) has written an article on the use of steel in aeroplane construction, as carried out at the factories of the Curtiss Aeroplane Company, Buffalo, N.Y.

W. H. Hatfield (*Paper read before the Aeronautical Society of Great Britain*, April 18, 1917) discusses the use of steel in aeronautical construction. A selection of steels is given, showing the large range of composition of the material now available for such purposes. The approximate mechanical properties of these typical steels, after subjection to various kinds of treatment, are also tabulated; the tests to be applied to such steels are discussed, the object of their application defined, and notes on the heat treatment and the purposes of such treatment are given.

Steel Tubing for Use in Aeroplane Construction.—J. S. Macgregor (*Aero World*, 1916, vol. 1, pp. 46–50; *Journal of American Society of Mechanical Engineers*, 1916, vol. 38, p. 1033, Abstract) states that steel tubing is rapidly finding its way into use in aeroplane construction. Nickel steel with 3·5 per cent. nickel is not thought to have any advantage over a 0·35 per cent. carbon steel with about 0·6 manganese. There has been a tendency to use tubing of extremely small wall thickness. A table shows the results of a number of tests in which the outside diameter of the tube was kept constant, and the wall thickness, starting with approximately 0·02 inch, was increased by increments of 0·02 inch up to 0·10 inch. It was found that the fibre stresses developed by the tubing increased with increase of wall thickness. A wall thickness of about 5 per cent. of the outside diameter develops the full strength of the material of which the tubes are composed.

Rail Corrugation.—T. N. Jones, Jun. (*Electric Railway Journal*, 1916, vol. 48, pp. 67–68), after studying various rail tracks on different types of foundations, concludes that a track on a resilient foundation is superior to one on a rigid foundation, in retarding corrugation of the rails. Instances are given establishing the certainty of the author's conclusions.

A further investigation arising out of Jones' tests has been carried out at Chicago (*Electric Railway Journal*, 1916, vol. 48, pp. 1012–1016). The conclusions do not bear out Jones' theory, but the corrugation of rails is attributed to a cold-rolling action, which is particularly marked when new rails are first laid.

Rail Failures.—The American Railway Engineering Association has issued its report as to the rail failures in the United States and Canada for the year ended October 31, 1915. The figures in the report prove two facts: (1) That the proportion of Bessemer rails put into the roads between 1913 and 1915 was gradually getting smaller; and (2) that the number of failures of Bessemer rails between 1910 and 1913 was about 50 per cent. in excess of the open-hearth rail failures. The actual figures given are as follows: In 1913 the tonnages of rails put into the roads were 122,974 tons of Bessemer, and 1,403,848 tons of open-hearth rails. In 1914 the Bessemer tonnage was 52,837 tons, the open-hearth 976,852 tons. In 1915, the Bessemer had 13,295 tons, the open-hearth 621,603 tons. As to failures, for every 100 failures of open-hearth rails rolled in 1910 there were 154 in the Bessemer rails rolled in the same year, 155 in the 1911, 143 in the 1912, and 142 in the 1913 rails. It is probable, moreover, that the open-hearth rails were, in general, in more severe service.

Tests of Car Axles.—R. N. Hemming (*Electric Railway Journal*, 1916, vol. 48, pp. 1025–1026) describes a method of testing car axles for cracks, flaws, or fractures. The axle is stripped, cleaned with petrol, and painted with lamp-black or plumbago, which is afterwards carefully wiped off and a coat of white lead applied. It is then suspended about 3 feet above the floor by a sling about the centre and a blow is struck near the centre. The sledging will render visible any flaw which exists, no matter how small, because the lamp-black shows through the white lead at once.

Strength of Pin Joints.—W. A. Scoble (*Paper read before the Institution of Naval Architects*, March 28, 1917) describes the results of experiments made to determine the proportions of the pin joint of greatest efficiency, the proposed design being based on the ultimate strength of the material.

Steel Conductors for Electric Transmission Lines—The possibility of using steel wires and cables for electric transmission lines was discussed by H. B. Dwight in a paper before the Association of Iron and Steel Electrical Engineers at Chicago (*Iron and Coal Trades Review*, January 1917, vol. 94, p. 16). The effective resistance and reactance of iron and steel conductors increase to a maximum as the current is increased and then decreased. In most cases, especially with larger cables, the decrease is slow and the resistance is maintained approximately at its maximum value for most large values of current. This property may prove useful in transmission line work for conductors where there is low impedance with a normal load current, but about double the impedance to a current flowing as the result of a short-circuit. The higher conductivity of steel for direct current than for alternating current makes the use of bare steel cables for direct current

often more economical than for alternating-current lines. The steel cable has eight times the resistance to direct current that a copper cable of the same size has, and seven times the resistance of a copper cable of the same weight. Inasmuch, however, as galvanised steel cables usually cost less than one-seventh as much as copper cables per pound, they should be more economical, other things being equal.

Copper-Clad Steel Wire.—Some notes on the manufacture and properties of "copper-weld" wire are published (*Electric Railway Journal*, 1916, vol. 48, pp. 409–410). The wire is manufactured from a steel bar about 4 inches diameter, 30 inches long, which is pickled, cleaned, and covered with a specially prepared flux. It is then placed in a mould, leaving an annular space, ½ inch in width round the bar, and mould and bar are heated in a furnace, and on reaching the proper temperature molten copper is poured over the bar, filling the space between bar and mould. The bar is then reheated, rolled, and drawn into wire. The weld between the copper and the steel is said to be absolute.

Cast Steel Wheel with Manganese Tread and Flange.—A description is given (*Foundry Trade Journal*, October 1916, vol. 18, p. 540) of a cast steel wheel with a manganese steel tread and flange and a ductile steel plate round the hub, which has recently been introduced by the American Steel Foundries of Chicago. Its durability is similar to that of a cast steel wheel, or even better, because of the tough wheel-tread and flange produced by manufacturing them of manganese steel.

Tests of Drill Steel.—F. H. Kaiser (*Engineering News*, March 22, 1917, pp. 479–480) presents some suggestions for selecting and testing drill steel for rock drills. The heat treatment suitable for such steel and the average analysis are given.

Critical Speed of Shafts.—A. Stodola (*Schweizerische Bauzeitung*, 1916, vol. 68, pp. 197, 209) publishes some observations on the critical speed of shafts. The deflections at critical speed are not infinite, but the values always remain finite even when the shaft is free and without support at one end.

Magnetic Properties of Iron.—R. Bown (*Journal of the Franklin Institute*, January 1917, vol. 183, pp. 41–59) has studied the characteristics of iron in high-frequency magnetic fields. Experiments which showed an apparent decrease in the permeability of the iron with an increase in the frequency of the magnetic cycle furnished a basis for a theory that iron was magnetically sluggish. Further and more accurate experiments proved, however, that the effects which had previously been ascribed to a peculiarity of the material were in reality caused by eddy currents in the sample. Furthermore, it was found

that, due to eddy currents and the magnetic properties of iron, the magnetisation in high-frequency fields was confined to a thin surface layer of the piece. This "magnetic skin effect" reduced the cross section of the iron which was magnetically active, even though the laminations were extremely thin. Careful experimental measurements compared with theoretical calculations proved that the real permeability of iron remained unchanged at frequencies up to about 10^{-6}, and that previous results had been in serious error due to neglect of the factors mentioned.

Testing Permanent Magnets.—G. B. Betteridge (*Electrician*, 1916, vol. 78, pp. 213–215) has devised an apparatus for the commercial testing of magnets. A batch of magnets can be tested for coercive force and remanence at a rate of 30 to 45 seconds per magnet, with an extreme error of 2 per cent.

Chromium Steel for Magnets.—E. Gumlich (*Mitteilungen a. d. Physikalisch-Technische Reichsanstalt*) has investigated the suitability of chromium steel for permanent magnets as a substitute for tungsten steel, tungsten having become practically unobtainable. Details of analysis and heat treatment have been withheld from publication. The results showed that carefully prepared chromium steel is a suitable substitute for tungsten steel.

Resistance of Iron Solutions.—E. D. Campbell (*Paper read before the Faraday Society*, December 18, 1916) has carried out a series of experiments to determine whether equiatomic solutions in iron possess equal resistances. The one striking point to be noted in his results is the almost constant value of the absolute increase in specific resistance with increased temperature, at which the specific resistance is measured, this increase differing very slightly from that of pure iron. These results would indicate almost beyond question that the increase in specific resistance with increased temperature of measurement is practically wholly due to the increase in specific resistance of the solvent, while the component of the total specific resistance due to the solutes in solid solution is very slightly, if at all, affected by the temperature at which the specific measurements are made.

Spontaneous Generation of Heat in Recently Hardened Steel.—It is shown by C. F. Brush and Sir R. A. Hadfield (*Proceedings of the Royal Society*, A, 1917, vol. 93, pp. 188–211) that various kinds of steel, including carbon tool steel, high-speed tungsten chromium steel, and other similar alloys, after being quenched at a high temperature and hardened, spontaneously generate heat for several weeks in appreciable and measurable quantity, the rate of generation of course steadily diminishing. The explanation would be that the specimens in quenching necessarily do not cool at an equal rate throughout their

mass. The interior, by cooling somewhat slower, does not acquire quite the same degree of hardness, nor therefore does it expand to the same extent as the exterior. Some adjustment therefore must go on. No doubt breakages in large masses of steel are due partly to the expansion on hardening, and they cannot expand equally throughout the mass.

Structure of Steel during Solidification.—H. M. Howe (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 623–625) deals with the formation of columnar and of free crystals in steel ingots during solidification. Each molten particle in the act of freezing splits up into a part poorer in carbon, which freezes, and a part richer in carbon which, because its enrichment in carbon lowers its freezing point, fails to freeze. This arrest of the freezing point is, however, only temporary, and the portion in question would freeze in due course but for the fact that its freezing point is raised up to the existing temperature by the shoreward diffusion of unenriched deep-sea metal. This dilutes the carbon content of the littoral layer enough to raise its freezing point up to the now existing temperature, when in turn it freezes. This diffusion feeds the freezable deep-sea metal faster to the tips of the pine-tree crystals which protrude from the already solid shores into the molten mass, than to their lateral branches, so that the growth tends to take place fastest at these tips. Hence the columnar form. The use of chill moulds hastens the cooling, and thus favours the growth of the tips of the existing pine-tree crystals, or in other words, of the columnar structure. The reason of the transition from the columnar to the equiaxed region is then explained, on lines of similar reasoning.

Grain Growth in Mild Steel.—R. H. Sherry (*Paper read before the Faraday Society*, December 18, 1916) deals with grain growth in mild steel. In his experiments he adopted as a standard of measurement the reduction in area of the wire or strip by cold work, as it is a matter of extreme difficulty to ascertain with any degree of accuracy a measurement of the stress applied. Grain growth in sheet may be eliminated by annealing hot rolled sheet at a temperature somewhere above 900° C., and if the sheet is then cold rolled the temperature of subsequent annealing should be kept below 650° C. Sheet treated in this manner may be somewhat stiffer than ordinary annealed cold-rolled sheet, but can be strained to a considerable degree before annealing becomes necessary. The practical difficulties of annealing sheet at the high temperature may be eliminated by box annealing. An important conclusion is stated in regard to cold-rolled strip steel, viz. that grain growth can be prevented by the use of reductions of area above 25 per cent. Where grain growth has occurred and refining becomes necessary, heating above 900° C. will bring about complete refining of the grain. If the scale produced at this high temperature should be troublesome,

the material may be quenched in water and subsequently annealed at 540° to 675° C. if necessary. In some cases annealing at 790° C. will produce a grain refinement sufficient to prevent further trouble.

Z. Jeffries (*Bulletin of the American Institute of Mining Engineers*, No. 119, 1916, pp. 2063–2073) deals with grain growth in metals and the factors which accelerate or retard it. The term "germinative temperature" suggested by H. M. Howe is substituted in the discussion of the results of the investigations carried out for the original term "critical temperature for grain growth." The factors chiefly influencing fast growth are rate of heating, the inherent resistance to grain growth in the pure predominating constituent, the size of grain prior to deformation, the temperature and deformation gradients, and the thickness of the samples. Fast-growth phenomena in low carbon steel are considered and discussed in the light of recent investigations, as well as the effect of cold deformation on the uniformity of orientation of original grains.

Metallographic Methods.—P. D. Merica (*Philosophical Society of Washington*, November 27, 1915; *Journal of the Washington Academy of Sciences*, 1916, vol. 6, p. 129) considers that the term metallography connotes in its general sense the study of the structures of metallic substances and the properties of such substances in relation to structure. It has often been confused with the microscopic study of metallic substances. Various applications of metallography to practical metallurgical problems are instanced and a method for determining structural identity or difference according to Hanemann is described.

Precipitation of Free Carbon in Irons and Steels.—W. H. Hatfield (*Proceedings of the Cleveland Institution of Engineers*, 1915–1916, pp. 135–146) gave an exposition of the laws underlying the precipitation of free carbon throughout the iron-carbon system, demonstrating, as the broad principle, that it is necessary for free carbide to have been in existence before free carbon can appear, since wherever free carbon, either as annealing carbon in the nodular form or as graphite in the well-known plates, appears, carbide must have been the first phase. The lecture was illustrated by numerous photomicrographs shown as lantern slides.

Pseudo-Eutectic Temperature of Iron-Carbon Alloys.—O. Ruff and W. Bormann (*Ferrum*, 1915, vol. 12, pp. 124–126) term the true eutectic temperature that at which iron (in the form of mixed crystals) and cementite separate, solid, in the same proportions in which they existed in the molten mass, while the pseudo-eutectic temperature is that at which the liquid is simultaneously saturated for mixed crystals and graphite. The pseudo-point was determined by the authors on an iron containing 4·13 per cent. carbon and was found to be 1138·8 $\pm$ 1° C. The point is slightly lowered by the presence of manganese and raised by that of silicon, and is very sharply defined.

The Iron-Carbon-Oxygen System.—W. Reinders (*Proceedings of Koninklijke Akademie*, Amsterdam, 1916, vol. 19, pp. 175-188) has studied the three binary systems of the iron-carbon-oxygen system, and on the basis of the results discusses the equilibrium of the iron-carbon-oxygen series from a theoretical standpoint.

Position of Martensite in the Iron-Carbon Diagram.—W. Broniewski (*Comptes Rendus*, 1916, vol. 162, pp. 917–919) regards martensite as a transition substance, and it therefore has no place in the iron-carbon diagram, although its marked crystalline appearance would indicate that it is a well-defined body stable within a certain temperature range. The results of comparative tests of the conditions of equilibrium show that martensite diminishes the free electromotive force of the ferrite in which the carbon is dissolved. Martensite is to be regarded as a solid solution of carbon, or cementite, in α-iron, with a region of stability at a temperature lower than that of annealed steel. The limiting concentration, which is below 0·05 per cent. carbon at the ordinary temperature, increases rapidly as the temperature falls, in accordance with a diagram shown in the original. It is probable that martensite obtained by quenching only becomes stable at about the temperature of liquid air, evidence of which is afforded by the tendency of austenite to revert to martensite when quenched in liquid air.

Apparatus for Recording Critical Points.—An apparatus for recording thermal transformation points is described, with diagrams of transformation-point curves for low-carbon chrome-vanadium steel and nickel steel and high-carbon nickel steel. The method consists essentially in heating a small sample of the metal in contact with a larger neutral body and simultaneously measuring the temperature of the sample by a thermometer and the temperature difference between the sample and the neutral body by a difference thermocouple while the furnace is being slowly heated and cooled. A transformation-point indicator, which constructs its own graphical chart, has been developed in connection with the appliance (*Metallurgical and Chemical Engineering*, 1917, vol. 16, p. 165).

An illustrated description is given of the Gibb "crit point" instrument, the use of which is based on the fact that steel, in the process of heating, loses its magnetic properties when brought to its critical point. Through the medium of electromagnetic coils the magnetic condition of the steel in the furnace is determined (*Metallurgical and Chemical Engineering*, 1917, vol. 16, p. 55).

An apparatus has been designed by the Leeds and Northrup Company, Philadelphia (*Iron Trade Review*, vol. 60, 1917, p. 147) for the location of thermal transformation points, which is intended to fulfil the stringent requirements of metallurgists in heat-treating processes. The method consists in heating a small sample of the metal

in contact with a larger neutral body and simultaneously measuring the temperature of the sample by a thermo-couple and the temperature difference between the sample and the neutral body by a different thermo-couple while the furnace is being slowly heated and cooled. The apparatus plots these two quantities as co-ordinates upon a rectangular chart. The critical temperatures are easily recognised on the chart from the slope changes of the curve.

Melting Points of Metals.—E. Jänecke (*Zeitschrift für Physikalische Chemie,* 1915, vol. 90, pp. 257-264) describes an electrically heated press first designed for investigating fusion points of natural and artificial potassium salts, but which has been adapted for determining melting points and transition phenomena of metals and alloys. Pressures up to 30,000 kilogrammes can be obtained, and the apparatus consists of a vertical steel cylinder 140 millimetres high and 30 millimetres diameter, in which three steel blocks are superposed. The substance rests on the upper block underneath the plunger. The three blocks are perforated so that the melting substance can flow down, but solid particles cannot drop. A chrome-nickel resistance furnace is slipped over the press, the temperatures being measured by a copper-constantan couple.

Spectrum of Iron.—G. A. Hemsalech (*Comptes Rendus,* December 11, 1916) has studied the grouping of the lines of the iron spectrum under the selective influence of thermal and chemical actions. The lines can be arranged in three groups: lines emitted by the external flame of a Bunsen burner and reinforced in flames of higher temperature; lines produced under the influence of chemical actions; and lines of the supplementary spectrum.

Some preliminary results obtained from a spectrum of iron burning in the oxy-hydrogen flame were communicated to the Royal Society by Sir N. Lockyer in 1911. A further paper by Sir N. Lockyer and H. E. Goodson (*Proceedings of the Royal Society,* A, 1916, vol. 92, pp. 260–265) contains an account of a continuation of the work on the same spectrum carried out on glass negatives taken from a copy, also on glass, of a spectrogram secured with the 3-inch Cooke prism spectrograph of the Solar Physics Observatory. In this spectrum 64 lines of iron have been identified between λλ 3856·52 and 5615·88; 15 of these lines have not hitherto been recorded in the iron flame spectrum.

Melting Point of Manganese.—The melting point of 97 to 98 per cent. pure carbon-free metallic manganese, which is often used in the manufacture of nickel alloys, is considerably lower than that of pure iron, the two differing by from 225° to 250° C. A recent booklet of the United States Bureau of Standards gives the following determinations of melting points: 97 to 98 per cent. pure manganese metal carbon-free, 1255° C.; pure iron, 1478° to 1533° C. (*Mechanical Engineer,* 1917, vol. 39, p. 120).

Specific Heats of Silicon Compounds at High Temperature.—W. P. White (*Paper read before the Philosophical Society of Washington*, November 25, 1916) has investigated the specific heat at high temperatures of certain silicon compounds. The charges were heated usually in electric furnaces. The high-temperature measurements in the furnace were made quite satisfactorily, first by means of regulators which held the furnace temperature constant; second, by measuring the temperature at the centre of the charge and keeping the furnace temperature uniform by means of platinum-faced partitions and a suitable arrangement of the furnace winding. The specific heats show in general a curvature concave to the x-axis, which is the upper part of an S-shaped curve characteristic of all substances. The curves show that the silica and silicon compounds investigated have atomic vibration periods of high frequencies comparable with those characteristic of the atoms of the diamond, whose specific heat curve is similar. These vibration frequencies are due to the oxygen in the compounds and are characteristic of oxygen compounds generally.

Poisonous Gases from Ferro-Silicon.—N. S. Kurnakoff and G. G. Urasoff (*Zeitschrift für angewandte Chemie*, 1916, vol. 29, p. 458; *Journal of the Society of Chemical Industry*, 1916, vol. 35, p. 1159) point out that on cooling molten iron-silicon alloys containing from 33·4 to 100 per cent. silicon, a solid phase ("Lebeauite") of varying composition crystallises out at 1243° to 1245° C.; when aluminium and phosphorus are present, ternary or quaternary solid solutions are formed. The ternary systems (Fe-Si-P and Fe-Si-Al) are not affected by water, but the quaternary solid solutions containing both phosphorus and aluminium are decomposed by water with evolution of hydrogen phosphide, and disintegrate when exposed to the air. The evolution of poisonous gases from commercial ferro-silicon containing 33·04 per cent. silicon is attributed to the presence of this unstable quaternary solid solution. In alloys of lower silicon content, phosphorus (up to 1·7 per cent.) and aluminium (up to 3 per cent.) occur as constituents of the γ solid solution of silicon in iron, and only insignificant quantities of hydrogen phosphide are produced from such alloys. Calcium phosphide is not soluble in either liquid or solid ferro-silicon, and the quantity of hydrogen phosphide evolved from commercial ferro-silicon is always considerably greater than that corresponding to the calcium content of the alloy.

Electrolytic Behaviour of Tungsten.—W. E. Koerner (*Paper read before the American Electro-Chemical Society*, September 1916; *Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 40–47) discusses the electrolytic behaviour of tungsten. The various attempts and proposals for extracting tungsten from its ores by solution and electro-deposition are reviewed, but the author comes to the conclusion that the investigators usually obtained not pure metal but a sub-oxide.

Details are given of a number of experiments undertaken to elucidate the electrolytic behaviour of tungsten, and a bibliography is attached to the paper. The author finds that tungsten dissolves anodically in aqueous and non-aqueous solutions of alkalies, acids, and salts, and tungsten anodes become passive in such solutions, the passivity being due to adherent films of hydrated tungsten oxides.

Corrosion of Cast Iron.—O. Bauer and E. Wetzel (*Mitteilungen aus d. Königl. Materialprüfungsamt*, 1916, vol. 34, pp. 11–40) deal with the corrosion of cast iron. Cast iron embedded in moist soil is subject to a peculiar form of corrosion, known as "graphitisation," "iron cancer," &c., in which it is converted locally into a soft, friable grey mass. The authors have investigated a number of cases of corrosion of this type, and their results indicate that the fundamental condition for such corrosion is the presence of water in the liquid state. The phenomenon is usually associated with grey cast iron, but white cast iron may be corroded in a similar manner. The corrosion is accelerated by the application of an electric current, or stray currents in the soil, but also takes place, though much more slowly, in the absence of external electric currents. The oxidation products of the iron, in a spongy condition at first, are retained in place by the network of graphite in the case of grey cast iron or of cementite in the case of white iron, and are gradually agglomerated to a more or less firm mass. In grey cast iron the corrosion appears always to proceed from the laminæ of graphite and gradually to spread outward.

Corrosion of Steel Sheets.—A preliminary report on corrosion tests of iron and steel is published (*Proceedings of the American Society for Testing Materials*, 1916, vol. 16, Part I., pp. 153–170). About 800 steel sheets, commercial products, have been supplied representing eight types of steel. These have all been analysed, and the analyses are given in full, preparatory to proceeding with the corrosion tests.

In a discussion of the subject of corrosion of commercial iron and steel sheets, at a recent meeting of the American Electro-Chemical Society, in New York (*Iron and Coal Trades Review*, November 1916, vol. 93, p. 545) the following conclusions were arrived at by E. A. Richardson and L. T. Richardson: (1) Copper-bearing steels are decidedly superior to pure iron, steel, or charcoal iron. (2) The addition of copper to pure iron increases its resistance to corrosion, but not to the same extent as with steel. (3) Charcoal iron and pure iron are superior to steel as regards resistance to atmospheric corrosion. (4) Charcoal iron is very similar to pure iron in its resistance to corrosion. (5) Copper is believed to reduce corrosion owing to some mutual influence of manganese and copper. (6) The additions of larger amounts of manganese and copper to pure iron or steel are suggested, as well as additions of copper-chromium, copper-vanadinm, copper-tungsten, or copper-molybdenum. (7) Mill scale stimulates

corrosion in rapidly rusting materials and retards it in slowly rusting materials.

Corrosion Resistance of Copper Steel.—Recent tests made in order to obtain definite information as to the influence of the presence of varying amounts of copper and other elements, when alloyed with steel, on the corrodibility of the latter, have led to the following conclusions: (1) Copper increases the resistance of steel and iron to atmospheric corrosion. Its influence is apparent when the copper content reaches only 0·03 per cent. Its effect is almost at a maximum when the copper reaches 0·05 per cent., and the best amount of copper for commercial steel has been found to be 0·25 per cent. (2) Steel containing 0·25 per cent. copper outlasts "pure iron" containing 0·04 per cent. copper. (3) Steel containing 0·05 per cent. copper lasts as long as "pure iron" containing 0·04 per cent. copper. (4) Sulphur in steel accelerates corrosion very markedly. (5) Sulphur-oxides in the air accelerate the corrosion of steel. (6) Copper in steel counteracts or retards both the corroding influences noted in 4 and 5 (*Foundry Trade Journal,* August 1916, vol. 18, p. 429).

Influence of Cobalt, Nickel, and Copper on Corrosion.—H. T. Kalmus and K. B. Blake (*Iron Age,* 1917, vol. 99, p. 201) describe an investigation on the effect of various percentages of cobalt, nickel, and copper on pure ingot iron, with special reference to their influence on corrosion. The additions were made to ingot iron melted in crucibles in a small electric furnace. It was found that alloys with these additions were more resistant to corrosion than pure American ingot iron. The additions to which these conclusions refer vary from 0·25 per cent. to 3·0 per cent.

Corrosion and the Electrical Properties of Steels.—Sir R. A. Hadfield and E. Newbery (*Proceedings of the Royal Society,* A, 1917, vol. 93, pp. 56–67) have studied the relation between the corrosion and electrical properties of steels. Corrosion tests were made on fifteen steels by the electrical method, by corrosion in acid, and by atmospheric corrosion. In four cases only does the electrical method agree with atmospheric corrosion, and in one case only with acid corrosion. The deviations are also much greater between the electrical and the acid corrosion.

Protective Coatings.—A rust-proof coating for iron and steel was a few years back patented by G. F. Wescott (*Foundry Trade Journal,* November 1916, vol. 18, p. 601), and is in the form of a paint that is applied to the surface of the article to be treated and then baked. The proportions of the ingredients by weight are: Linseed oil, 25 parts; calcium resinate, 36 parts; manganese borate, ½ part; sugar of lead, 1 part; naphtha, 37½ parts; artificial graphite, 25 parts. The

whole is mixed and applied to the steel or iron by brushing, dipping, or other procedure. The article is then baked at 300° F. for an hour and forty minutes. The coating is lustrous and resistant to corrosive influences.

Epicassit: Process for Protecting Steel Surfaces.—H. Hess (*Metallurgical and Chemical Engineering*, 1917, vol. 16, p. 13) advocates the employment of a new coating process for metals in which zinc, reduced to fine powder and free from oxide or other impurity, is mixed in a paste and applied to the cleaned surface of the metal to be coated, the latter being then heated to slightly above the melting point of the zinc. For tough and ductile coatings that will resist bending, twisting, and hammering, tin and lead are added to the pulverised zinc. The process, which is termed Epicassit, gives a bright, smooth coating which is very adherent, and can be applied with great ease.

Lead-Plated Metal Parts.—The substitution of lead-plated steel for zinc and nickel-plated material and phosphor-bronze, copper, and brass parts, used where metal must be protected from corrosion caused by acid, salts, and fumes, has been made possible by the development of a process for lead plating that is being used by the United States Electro-Lead Plating Company, Cleveland, Ohio (*Foundry Trade Journal*, August 1916, vol. 18, p. 436). The Willard Storage Battery Company has equipped a large plating plant in which the new process is used for plating grey and malleable-iron castings and steel stampings. From 15,000 to 20,000 parts are lead-plated every day, these being used for battery handles, screws, top connections, and terminals.

CHEMICAL ANALYSIS.

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I.—*ANALYSIS OF IRON AND STEEL.*

Estimation of Carbon in Steel.—J. W. Barbey (*Iron Age*, 1916, vol. 98, p. 1053) gives a rapid method for the estimation of carbon in steel suitable to works practice where a large number of estimations have to be made in a relatively short time. The method consists in systematising the ordinary direct-combustion process with absorption of the calcium carbide by potash, but the various stages have been so adjusted that ten complete operations can be made in an hour.

Estimation of Boron in Boron Steel.—C. Aschman, Jun. (*Chemiker-Zeitung*, 1916, vol. 40, pp. 960–961; *Journal of the Society of Chemical Industry*, 1917, vol. 35, p. 1263) gives the following method for the determination of boron in boron steel. The steel (1 to 3 grammes) is dissolved in dilute sulphuric acid in a flask beneath a reflux condenser, care being taken to avoid too large an excess of acid. The solution is transferred to a distillation flask, and the flask is connected with an inverted condenser, the end of which passes through a cork in a receiver containing a solution of 0·5 gramme of pure ammonium carbonate in 20 cubic centimetres of water, with a few drops of ammonia. The outlet tube from the receiver dips into a beaker of water. The distillation flask is heated on a sand bath until nearly the whole of the liquid has distilled. The apparatus is then allowed to cool a little, 10 cubic centimetres of absolute methyl alcohol (free from acetone) introduced, and the liquid distilled. This operation is repeated five times, a slow current of air being passed through the apparatus for some minutes after each addition of methyl alcohol, and for fifteen minutes after the final distillation. The distillate is evaporated in a platinum basin containing 1 gramme of ammonium phosphate, and the residue is gradually ignited in an electric oven and kept at about 1000° C. until the boron phosphate becomes constant in weight.

Rapid Determination of Phosphorus in High-Speed Steels.—E. C. Kraus (*Iron Age*, March 1917, vol. 99, p. 527; *Mechanical Engineer*, April 1917, vol. 29, p. 328) has devised an accurate and rapid method for the determination of phosphorus in high-speed steels. Excellent results are reported on Government standards containing various amounts of tungsten and vanadium. The following is a description of the method: Dissolve 2 grammes of the sample in 1 to 3 aqua regia, and when the solution is boiling quietly, add a few crystals of potassium chlorate. Evaporate to about 20 cubic centimetres. Then remove from the hot plate, add 40 cubic centimetres of water, cool under tap, and filter, washing twice with 1 to 1 hydrochloric acid. Next, evaporate the solution to the basic ring. Again remove from the plate, wash down the sides of the beaker with about 25 cubic centimetres of water, cool, and filter. Transfer the solution to an Erlenmeyer flask, and after neutralising with 10 cubic centimetres of ammonia and adding 15 cubic centimetres of nitric acid, precipitate immediately with molybdate solution. If vanadium is present, reduce with 5 cubic centimetres of 3 per cent. sulphurous acid just before adding the molybdate. Allow the solution to stand forty-five minutes after thoroughly shaking. Then filter and determine the phosphorus by titration with standard acid and alkali solutions.

Co-operative Analysis of Low Sulphur Tool-Steel: Determination of Manganese.—A committee of the American Society for Testing Materials (*Proceedings*, 1916, vol. 16, Part I., pp. 123–128) submits a report on co-operative analysis of a tool steel. The sulphur determinations were made by fourteen laboratories, but the methods are not specified except those used in the laboratories of the General Electric Company of Schenectady. The sulphur contents reported by the other thirteen ranged from 0·008 to 0·022 per cent. The General Electric Company used four methods, one of which was the Bauer and Deiss ether-extraction method, with which two determinations gave 0·0137. The average of all the results was 0·0139. The same committee reports on procedure for standardising arsenite solutions for manganese determinations.

Estimation of Manganese.—E. Szasz (*Chemiker-Zeitung*, 1916, vol. 40, pp. 810–811; *Journal of the Society of Chemical Industry*, 1916, vol. 35, p. 1063) gives a method for the rapid determination of manganese in steel.

Estimation of Chromium in Ferro-Chromium.—A. F. MacFarland (*Metallurgical and Chemical Engineering*, 1916, vol. 15, p. 279) gives a simple, rapid, and accurate method for estimating chromium in ferro-chromium. The alloy is fused in sodium peroxide, the melt dissolved and boiled, acidified with sulphuric acid, and titrated with bichromate solution. The special precautions needful are detailed.

Analysis of Nickel-Chromium Alloys.—E. D. Koepping (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 319–321) gives details of a method for the analysis of nickel-chromium alloys and of the precautions to be observed in obtaining accurate results. The elements for which analytical methods are given are the silicon, nickel, chromium, manganese, iron, aluminium, sulphur, phosphorus, and carbon.

Estimation of Nickel.—G. L. Kelley and J. B. Conant (*Journal of Industrial and Engineering Chemistry*, September 1916, vol. 8, pp. 804–807; *Journal of the Society of Chemical Industry*, 1916, vol. 35, pp. 1018–1019) give a method for the volumetric determination of nickel in iron and steel.

Rate of Solution of Metals in Ferric Salts.—R. G. van Name and D. U. Hill (*American Journal of Science*, 1916, vol. 42, pp. 301–332) deal with the rates of solution of metals in ferric salts and in chromic acid.

Appliances for Steel Analysis.—G. L. Kelley (*Journal of Industrial and Engineering Chemistry*, November 1916, vol. 8, pp. 1038–1039) describes, with illustration, a new tube and a new absorbent for carbon dioxide in steel analysis.

E. Schramm (*Paper read before the American Electro-Chemical Society*, September 1916; *Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 574–577) reviews recent developments in scientific instruments and materials. The developments dealt with comprise measures of length, mass, and volume, electrical instruments, thermometers, and pyrometers, optical glass and instruments, metals such as platinum, chemical glass ware, and china and porcelain.

Training the Works Chemist.—F. E. Lathe (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 103–105) puts in a plea for the more practical training, in the college laboratory, of the works chemist, who will eventually have to work more especially with an eye to speed than to academic accuracy. The furnace-man requires to know in a few minutes the approximate composition of his steel—accurate results furnished a day later are useless to him. At the same time accuracy need not be sacrificed to speed, and the following points are noted as necessary to be followed in the training of a really efficient works chemist: (1) Thorough cleanliness and system. (2) Ability to conduct several determinations of a different character, simultaneously. This should, in particular, be engrafted during the college course. (3) The most accurate quick methods should be taught; the permissible error should be known, and needless accuracy sacrificed for a rapid result within this limit. (4) Helps to rapid work, mechanical contrivances, and shifts should be taught. (5) Judgment as to what may occur to mask results or impair accuracy should be developed.

Routine hints for work in hand are given, with an approximate time allowance for the work.

II.—*ANALYSIS OF ORES AND SLAGS.*

Sampling of Ores.—T. R. Woodbridge (*U.S. Bureau of Mines*, Technical Paper 86, 1916, pp. 1–96) has investigated the methods of sampling and analysing ores. The report deals with conditions affecting ore sampling, the methods and apparatus employed, the treatment of samples, and the comparison of assays. The ores under consideration are limited to those of metals other than iron.

Determination of Nickel.—P. Covitz (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 682–683) gives a rapid and accurate method for the determination of nickel in iron ores.

S. Rothschild (*Chemiker Zeitung*, 1917, vol. 41, pp. 29–30; *Journal of the Society of Chemical Industry*, 1917, vol. 36, p. 238) gives a method for the determination of nickel in the presence of zinc and iron.

Determination of Cobalt.—W. D. Engle and R. G. Gustavson (*Journal of Industrial and Engineering Chemistry*, October 1916, vol. 8, pp. 901–902) describe a new volumetric method for the determination of cobalt. As the quantitative determination of nickel and cobalt in the presence of one another is difficult, the investigation was undertaken to find simpler methods than those commonly used. A very satisfactory method for cobalt was found, but in the case of nickel nothing better than the methods already in use have so far been discovered. Cobalt may be determined in the presence of nickel by oxidation in alkaline solution with sodium perborate, removing the excess of the perborate by boiling, and after the addition of potassium iodide and dilute sulphuric acid, titrating with a standard sodium thiosulphate solution.

III.—*ANALYSIS OF FUEL.*

Determination of Moisture in Coal.—E. Mack and G. A. Hulett (*American Journal of Science*, 1917, vol. 43, pp. 89–110) describe methods of determining the moisture in coal.

Oil Analysis.—G. Egloff (*Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 259–263) points out that the rapid, safe, and accurate analyses of light oils resulting from the thermal decomposition of coal, shale, or petroleum oil for the benzene, toluene, and xylene they contain, is of considerable importance, and gives an illustrated description

of a still devised for the purpose and the method of using it. Specifications for benzene and toluene, having regard to their appearance, specific gravity, boiling point, and sulphuric acid test are also given.

Analysis of Toluene and Benzene in Coal-Tar Oils.—G. Harker (*Journal and Proceedings of the Royal Society of New South Wales*, 1916, vol. 50, Part I., pp. 99–105) refers to the difficulty in certain munition work undertaken for the Federal Munitions Committee of finding a satisfactory method for the estimation of toluene and incidentally of benzene in coal-tar oil. As the published methods showed considerable divergence it was necessary to make blank tests, after which the analysis of tar oil for the two constituents mentioned was successfully made, the method being fully described.

IV.—*ANALYSIS OF GAS.*

Analysis of Producer-Gas.—P. W. Swain (*Journal of the American Society of Mechanical Engineers*, 1916, vol. 38, pp. 978–982) describes methods and apparatus for sampling producer-gas and for its analysis. The Williams apparatus for analysis of producer-gas is shown, also the Orsat apparatus with explosion pipette. A diagram for solving quickly the equations giving the percentage of hydrogen, carbon monoxide, and methane is presented.

Determining the Density of Flue Gases.—J. A. Smith (*Paper read before the Victorian Institute of Engineers; Metallurgical and Chemical Engineering*, 1917, vol. 16, pp. 160–161) gives a method for determining the density of flue gases, based on the fact that the densities of gases and their pressures per unit area of base are directly proportional when their columns are of equal height. If a column of air in a vertical tube of known height be displaced by a given gas, the barometric and thermometric conditions remaining constant, the densities are in the simple ratio:

$$D = \frac{P \pm P'}{P}$$

when D=the density of the given gas referred to air taken as unity, P the known air pressure due to column height, and P′ the difference of pressure due to gaseous displacement. The method, based on these principles, is described in detail.

CO and CO_2 Recorder.—A new automatic recorder for graphically and continuously recording the percentage of oxygen-carbon monoxide, and carbon dioxide in industrial gases is described and illustrated with photographs and diagrams (*Metallurgical and Chemical Engineering*, 1916, vol. 15, pp. 542–544). The percentages are shown simultaneously on the same chart, and as many as sixty analyses can be made per hour with great accuracy. The apparatus is known as the Mono Purity Recorder.

ECONOMICS.

Iron and Steel Industries of Great Britain.—J. Horton (*Iron Trade Review*, 1917, vol. 60, pp. 54–56) reviews the iron and steel industries in Great Britain in the second year of the war.

Effect of the War on Metallurgical Industries of Canada.—A. Stansfield (*Transactions of the Canadian Mining Institute*, 1916, vol. 19, pp. 131–138) reviews the effect of the war on the metallurgical industries of Canada. For the first six months the metals produced in the country, such as lead, zinc, copper, aluminium, nickel, and silver, remained at their normal price, and even fell somewhat. After that period the need of these metals caused first one and then another to rise to phenomenal prices. The request from the British Government that Canadian manufacturers should produce some of the munitions required was ably met by the Shell Committee. Important developments of several molybdenite deposits have taken place; and after experimenting with the Belgian and French processes for the extraction of zinc, an electrolytic process for utilising the lead-zinc ores from the Sullivan mine has been installed at Trail; an output of 45 tons of zinc a day is expected to be attained. With regard to nickel, arrangements have been made between the Dominion Government and the International Nickel Company for establishing a refinery in Canada to meet the British needs of nickel. The author has developed a process for the manufacture of magnesium, and the commercial manufacture of that metal has been in operation for nearly a year.

T. Cantley (*Ibid.*, Bulletin No. 45, 1916, p. 25) deals with the effect of the war upon the Canadian iron and steel industries.

Mineral Resources of the British Empire.—C. G. Cullis (*Transactions of the Society of Engineers*, 1916, pp. 215–262) reviews the mineral resources of the British Empire, with special reference to the production of non-ferrous industrial metals. Statistics of production of copper, lead, zinc, tin, and aluminium are given.

German Iron Industry in 1915.—Statistics are given (*Zeitschrift für angewandte Chemie*, 1916, vol. 29, p. 697; *Journal of the Society of Chemical Industry*, 1917, vol. 36, p. 87) of the German iron industry in 1915. In the period July 1, 1915, to June 30, 1916, the production of pig iron in Germany was 12,756,000 metric tons, as compared with 10,633,000 tons in 1914–15, an increase of 20 per cent.; the 1915–16

production amounted to 67 per cent. of that of 1913–14, the highest previously recorded. The steel production was 14,790,016 tons in 1915–16, as against 11,752,627 tons in 1914–15, an increase of 25·8 per cent. and 82·6 per cent. of the highest production previously recorded. The total coal production was 87,800,000 tons in 1915–16, as against 77,000,000 tons in 1914–15, and the available supply, after deducting that consumed at the mines, was 68,400,000 and 60,600,000 tons in 1915–16 and 1914–15 respectively. The amount of steel rolling-mill products fell from 3,393,537 tons in 1914–15 to 3,279,632 tons in 1915–16. The year was a very profitable one for the companies concerned. In nearly all cases the profits were higher than any previously recorded —twice, and in many cases three times, as much as in the previous year. Dividends were increased, and large sums were applied to writing off capital and providing special reserves in preparation for the severe competition anticipated after the war. The high profits were due largely to increased prices. Female labour and workers from occupied enemy territories have been used in an increasing degree during the past year.

German Cartel System.—A general survey of the policy and methods of conducting the operations of the German iron, steel, and metal combines has been prepared, together with a report on the German Pig Iron Association, by C. Copland Perry (1916). The same author has also compiled a report on the development and operations of the Stahlwerksverband during the years 1912–15 and part of 1916.

Manufacture of Ferro-Silicon in Norway. — It is reported (*Foundry Trade Journal*, December 1916, vol. 18, p. 643) that the electro-chemical works at Hafslund, Norway, have considerably increased their output of ferro-silicon. The Hafslund Power Company, which owns the waterfalls and supplies the current, has now become a purely Norwegian concern, all the shares formerly held by the German Schückert firm, and representing three-quarters of the share capital, having been acquired by Norwegians.

Japanese Iron Industry.—According to H.M. Commercial Attaché at Yokohama, a Bill for the encouragement of the iron industry in Japan is being considered for presentation to the forthcoming session of the Diet. The principal points of the Bill are: (1) That the Land Expropriation Act be applicable to those iron foundries, refining plants included, which possess an annual capacity of 35,000 tons and above. (2) That, in the absence of special reasons, all Government-owned forests or lands be made available to such foundries by rent or sale. (3) That all persons undertaking to establish iron foundries be exempt from all forms of taxation for ten years, beginning with the year following the establishment of such foundries. (4) That all ores imported by such foundries be exempt from customs duty. (5) That all materials

employed in the construction of the plant be imported free of custom duties. (6) That products of iron foundries established in Corea be exempt from customs duties on importation into Japan (*Mechanical Engineer*, 1917, vol. 39, p. 70).

World's Iron Ore Reserve.—H. H. Campbell (*Iron Age*, 1917, vol. 99, pp. 51–53) estimates the iron ore reserves of the world as sufficient to last 800 years if the rate of pig iron consumption is constant. Of acid Bessemer ore enough is in reserve to make 1,500,000,000 tons of pig iron, and of available ore, unsuitable for either the acid or basic converter, enough to make 6,500,000,000 tons of pig iron. Details of the distribution, so far as the great continents are concerned, are given.

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